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doi:10.15199/48.2015.08.24

Performance Evaluation of routing algorithms used in large-scale WSN: A Step Towards A Smart City

***Abstract**. This paper presents the performance evaluation of the routing algorithms found in WSN networks that can be used as part of the Smart City concept, in order to identify the best candidate. The first part of the paper consists in a brief summary of the main routing techniques and mechanisms used in large scale WSN networks, while the second part of the paper will comprise an analysis of the Flooding, Probabilistic Broadcast and Convergecast algorithms. The performance evaluation consisted in a series of simulations, by means of the Omnet++ 4.3 simulation framework and the MiXiM framework. The obtained results show that, in terms of the latency parameters, the highest performance level is ensured by the Flooding routing mechanism, followed by the Convergecast and the Probabilistic Broadcast algorithms. In terms of the number of received packets, the highest throughput is provided by the Convergecast routing algorithm.*

***Streszczenie.** W artykule zaprezentowano algorytm routingu w sieci WSN wykorzystywanej jako element koncepcji Smart City. Analizowano algorytmy Flooding, Probabilistic Broadcast oraz Convergecast. Do analizy wykorzystano platformę symulacyjną Omnet++ 4.3 oraz MiXiM. Stwierdzono że najlepsze właściwości ma algorytm Flooding. Z punktu widzenia liczby otrzymywanych pakietów najlepszą przepustowość miał algorytm Convergecast. **Analiza parametrów różnych algorytmów routingu w sieci WSN przeznaczonej do realizacji koncepcji Smart City**.*

Keywords: WSN, Smart City, routing algorithms, Omnet++, Convergecast, Flooding, Probabilistic Broadcast.
Słowa kluczowe: Smart City, routing, Flooding, Convergecast

Introduction

The recent technological advances in wireless systems, accompanied by the reduction of power consumption made possible through the development of digital electronics and integrated devices has led to the development of micro-sensors [1-5]. These WSN (Wireless Sensor Networks) sensors have communication and data processing abilities, often being equipped with integrated sensors for monitoring the environment. The information collected by the sensors is sent for storage and subsequent analysis to the control centre. The diminishing size and cost of the WSN sensors has fuelled the spectacular development of the applications that can integrate them and has brought them to the attention of several research centres. This interest has also greatly motivated the research activities of the past years and the attempts to find solutions in terms of sensor collaboration, data collection and processing procedures as well as data coordination/management conducted by the central sink node [6]. These networks are expected to have a significant impact on the efficiency of several military and civilian applications, such as: emergency situations management, security provision and various monitoring and control applications.

These systems, process the information received from the sensors that monitor certain events in particular areas of interest. The main contribution of this paper is the evaluation of the performance of the routing algorithms that can be part of a Smart City concept.

Large scale WSN routing techniques and mechanisms used in the Smart City concept

WSN nodes have limited resources as concerns the processing power, the storage capacity and, last but not least, the energy resources and the ability to perform a limited information transfer. The implementation of WSN networks on a large scale and the augmentation of the performance level are the main issues that should be addressed. The main two power consuming sources of a WSN node are the communication process (transmission/receipt of the bits) and the local calculation processes that must be conducted by the respective node. Nevertheless, it is also well known that the information transfer capacity also entails a twice as high power consumption than the information storage procedures or the calculation and monitoring of the data received from different sensors. In light of this information, the manner in which communication is conducted must be made more efficient in terms of the power consumption [6].

A WSN node consists in a transceiver, a microcontroller and an energy source assembled in a very small sized unit. Fig. 1 presents the main components of a WSN module, such as: the power source, the sensing unit, the processing unit, the storage unit and the transceiver.

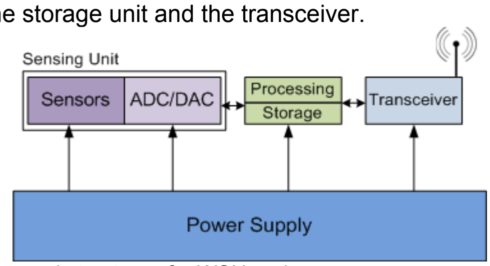

Fig.1. Internal structure of a WSN node.

The power source entails certain restrictions as concerns the power consumption allocated for the procedures, for storing the information, connectivity, bandwidth and calculation speed. These characteristics entail the presence of certain mechanisms for adjusting the size of the packets and meant to increase the efficiency of the network, the implementation of efficient routing algorithms thus being highly necessary. In light of these circumstances, one way to reduce power consumption is to improve the routing mechanisms. The IEEE 802.15.4 standard defines the MAC and the physical level of the WSN sensor networks, whereas the application and network levels are not specifically defined.

The coordinator and the routers are in charge of finding and maintaining the routes, as they are of the FFD (Full Function Device) type. A WSN End Device node has no routing capabilities, as it is of the RFD (Reduced Function Device) type.

However, WSN nodes have restrictions as concerns the power consumption, as they have a limited bandwidth. These restrictions, accompanied by the implementation of a very large WSN network are a challenge in terms of the design and management of such sensor networks. These challenges entail the implementation of a mechanism that would reveal the power consumption needs and it should be fitted at all levels of the communication stack.

The issues related to the physical level and to the communication link are generally common for all types of applications and, therefore, the research in the field has focused on the development of a dynamic system that would render power consumption more efficient by improving radio communication, the hardware, by designing systems with a low duty cycle and by implementing improved MAC (Media Access Control) protocols [7-11].

As far as networks are concerned, the main purpose of the research conducted in the past few years is to find a way to identify the best route in terms of power consumption, so as to extend the life cycle of the network. The question of routing algorithms entails the solving of difficult issues, since sensor networks have a particular structure that makes them different from other ad-hoc wireless networks. First of all, it is not possible to design a global addressing system for the implementation of a large scale WSN network and, therefore, the classical IP (Internet Protocol) address-based routing protocols cannot be applied within a sensor network.

Secondly, unlike other networks, almost all the applications of WSN networks require the collection of information from different sources to a sink node. Thirdly, the generated data traffic is redundant, since several sensors in the proximity can generate the same information. This data redundancy must be used by the routing protocols in order to improve power consumption and increase the use of the bandwidth. Fourthly, the sensors are restricted as far as their transmission power, available energy and ability to collect and store information and, therefore, require a careful management of the resources [6].

Due to these circumstances, several new routing algorithms have been suggested in the past few years. These mechanisms have considered the characteristics of the WSN nodes, as well as the requirements and the architecture of the application. Almost all routing protocols can be classified as data-centric, hierarchical or location based, even though there are a few other distinct protocols that are based on the quality of services (QoS- Quality of Service) [12].

Data-centric protocols are based on a data interrogation procedure that allows for the removal of redundant transmissions. Hierarchical protocols focus on grouping the nodes in clusters, so that the cluster conducting nodes can perform certain data aggregation and reduction operations in order to save power. The location-based algorithms use the GPS coordinates of the node to resent the information to certain regions, as opposed to sending it throughout the entire network. The last category comprises the routing protocols that require certain additional QoS criteria, apart from the packet retransmission mechanism.

We will further present an evaluation of the performance level of the routing algorithms that can be used as part of the Smart City concept in order to identify the best candidate.

2.1. Energy-Aware routing protocols

The use of a set of occasional suboptimal paths within a routing algorithm for increasing the lifecycle of the network is presented in [13]. These routing paths are identified by applying a probability function that depends on the power consumed for each separate route. The purpose of this algorithm is to maintain the sustainability of the sensor network. This approach entails that the consistent use of the same route will lead to the depletion of the power needed by the nodes that are part of the packet retransmission process. Thus, instead of a single routing choice, the algorithm suggests the use of multiple other routes with a certain probability, so as to extend the life span of the network. The protocol entails that each node can be addressed through a class that would include the node location and type.

The approached mechanism is similar to the Directed Diffusion algorithm [14], as the communication routes from the sink node to the source nodes are discovered. The drawback of the suggested algorithm is the inability to discover a route when one of the nodes malfunctions or when the communication path is no longer active, unlike the Directed Diffusion algorithm. Additionally, the algorithm suggests the collection of the information related to the location of the nodes and the implementation of an additional addressing mechanism that entails the route identification method.

In a large scale WSN network, extending across a wide geographical area, it is important to implement a routing algorithm that would increase the efficiency of power consumption and, at the same time, allow for the implementation of a simple mechanism, as the number of nodes can exceed several thousand.

2.2. The Convergecast routing protocol

The communication mechanism used as part of the Smart City concept is of the many-to-one type, as the WSN sensors are used for collecting information from the environment and then send it to a central sink node. This process of collecting the information from all nodes and then send it to the sink node is also called convergecasting, as can be seen in Fig. 2.

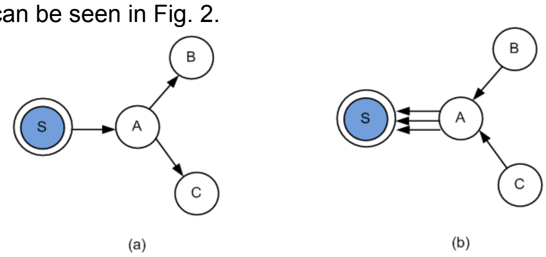

Fig.2. (a) Broadcast (b) Convergecast.

This routing protocol complies with the requirements of the communication mechanism used in the Smart City concept and is easy to implement, since the nodes do not need to maintain complex routing tables. Also the hardware resources of the WSN are quite low (e.g. the RAM memory).

2.3. Hierarchical routing protocols

Similarly to other communication networks, one of the main characteristics of the WSN sensor networks is scalability. The presence of a very large number of nodes can lead to gateway overloading, increased communication delays and even prevent the nodes from communicating. The architecture of the Smart City concept cannot include a single sink node that would collect the information (or a single Gateway node, implicitly) because the performance level will be very low. Professional literature provides information on a series of routing protocols that suggest dividing the WSN network into clusters.

The LEACH algorithm (Low Energy Adaptive Clustering Hierarchy) [7] is one of the first hierarchical routing mechanisms that enables the reduction of power consumption by up to 7 times, as compared to the direct communication mechanism, but the hardware requirements of the nodes are quite high.

2.4. Self-Organizing algorithms

A self-organizing protocol is presented in [5]. The proposed algorithm uses the router nodes that ensure connectivity to other nodes in the network by forming a dominant set. Since the nodes can be addressed individually, the proposed algorithm is suitable for the applications that require communication with a certain node, such as developing a system for managing parking lots as part of a Smart City concept. The main shortcoming is the presence of the organization stage that is not on demand and there are therefore additional delays, while the hardware resources of the WSN nodes are quite high.

2.5. Location based routing protocols

Most of the routing protocols developed for sensor networks are based on information about the location of the node. This information is needed for calculating the distance between two nodes, so that the power consumption can be estimated. Since there is no single addressing system for sensor networks, such as IP addresses, this information concerning the geographical location can enable the reduction of the consumed power resources.

However, as part of the Smart City concept, these issues would entail increased costs for the WSN nodes, as the hardware requirements would be even higher.

2.6. Flooding, Gossiping and Probabilistic Broadcast algorithms

The flooding and gossiping [15] routing mechanisms are two classical methods of transmitting information without any need for specialized routing algorithms or network topology management. The flooding algorithm entails that each sensor that receives a data packet should resend it through a broadcast method to all neighbouring nodes, and this procedure would continue until the packet reaches its destination or the maximum number of hops is reached. On the other hand, the Gossiping algorithm uses a more advanced flooding method, where the node that receives the packet sends the data to a randomly selected neighbour and the procedure will thus continue. Even if these mechanisms are very easy to implement, there are a series of problems, as can be seen in Fig. 3. The A node sends the information to all neighbouring nodes. Node D receives two packets that contain the same information from nodes B and C.

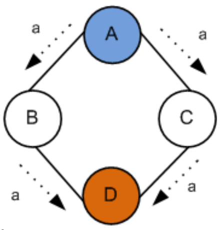

Fig.3. The implosion phenomenon

The drawbacks of the Flooding algorithm include the presence of the implosion phenomenon, caused by the duplicate messages sent to the same node, the overlapping phenomenon, when two nodes in the same region sent similar packets to the same neighbour, and the power resource consumption phenomenon. [15]. Fig. 4 presents the overlapping phenomenon. Node C receives the information from nodes A and B that monitor the same geographical area.

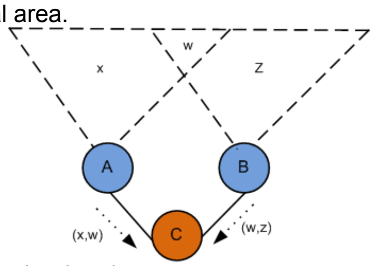

Fig. 4. The overlapping phenomenon.

The Gossip mechanism avoids the problem of implosion by selecting a random neighbouring node to which it can send the packet. One of the main disadvantages of the Gossip algorithm is the lack of a mechanism that would enable the reduction of the power consumption and the introduction of an additional delay due to the broadcast mechanism. Nevertheless, the flooding algorithm can be integrated in a metropolitan WSN network of the Smart City type, providing a significant advantage. Thus, it would no longer be necessary to implement complex routing mechanisms and the routing tables are eliminated. Therefore, WSN nodes need a smaller RAM memory, thus enabling the reduction of the implementation costs.

The communication mechanism of the probabilistic broadcast routing algorithm is similar to the gossiping algorithm. Thus, when a node wishes to send a message, it would do so through a broadcast mechanism to a set of randomly selected set of nodes. In turn, the nodes receiving the message will further resend it through broadcast to another set of randomly selected nodes. Thus, the algorithm ensures a high throughput, but each node must have communication routes with all the other nodes in the network. Thus the probabilistic broadcast algorithm ensures a high throughput and can also be implemented in the Smart City concept [16].

Evaluation of the performance of routing algorithms that can be integrated in the smart city concept

This section focuses on the evaluation of the performance of the network algorithms that can be integrated in a Smart City concept. As mentioned in the previous section, the Flooding, Probabilistic Broadcast and Convergecast algorithms have been considered. The performance evaluation has been conducted via a series of simulations by using the Omnet++ 4.3 framework [17] and the MiXiM [18] framework. Thus, several simulation scenarios have been implemented, by changing the number of nodes in the network. The routing algorithm must enable the integration of a large number of nodes, all the while ensuring as high a performance level as possible. The nodes have been randomly scattered on a geographical area of 25 x 25 km. Fig. 5 and Fig. 6 present the network topology created for 1000 WSN nodes (Fig. 5) and for 2000 nodes (Fig. 6). The number of nodes has varied between 500 nodes and 1000, 1500, 2000, 2500 and 3000 nodes respectively.

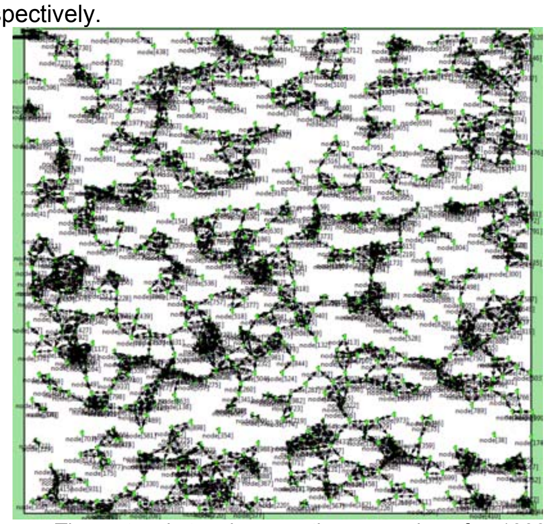

Fig. 5. The network topology routing procedure for 1000 WSN nodes.

The parameters under analysis in our study are: mean latency, number of received packets in the routing mechanism and average number of hops made by a packet before reaching its destination. The routing algorithms under consideration in this study are the Probabilistic

Broadcast, Flooding and Convergecast. These have been presented and analysed in the previous section, as the purpose of this research is to identify the best candidate that would ensure a high performance level and be successfully integrated in a Smart City concept.

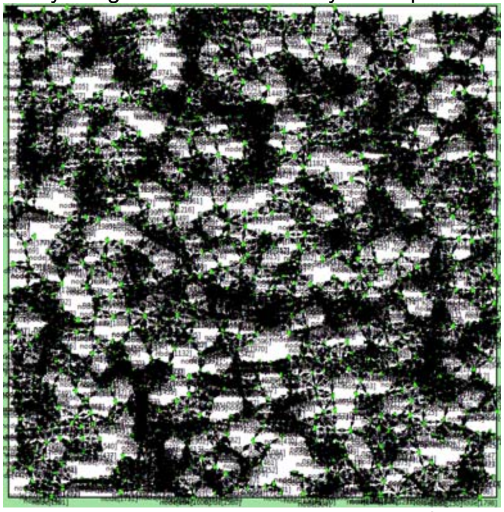

Fig. 6. The network topology routing procedure for 2000 WSN nodes

Results

Fig. 7 shows the evolution of the mean latency parameter as the number of WSN nodes increases in a metropolitan network when the Probabilistic Broadcast algorithm is used.

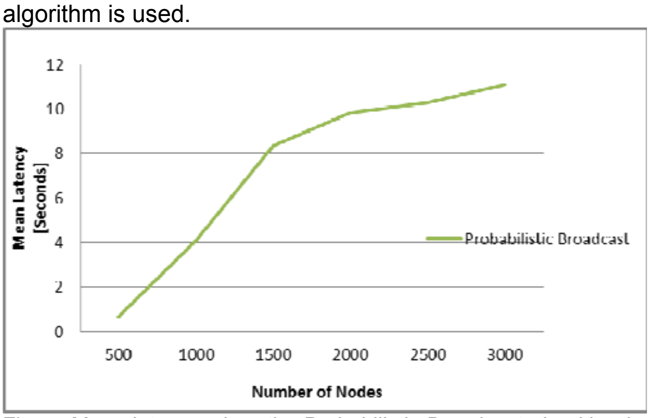

Fig. 7. Mean latency when the Probabilistic Broadcast algorithm is used.

Fig. 7 shows that the latency parameter increases as the number of WSN nodes increases. Thus, the mean latency parameter increases from 0,647 seconds for 500 WSN modules to 11,1 seconds in the case of 3000 modules. Thus, the Probabilistic Broadcast algorithm ensures a high throughput level and can be implemented in a Smart City concept.

Fig. 8 shows the evolution of the mean latency parameter when the Convergecast and the Flooding algorithms are used. Thus, for a network of 500 nodes, there will be a latency of 23,3 ms for the Flooding routing algorithm and of 43,4 ms respectively, for the Covergecast algorithm. In the case of a 3000 nodes network, the latency amounts to 298,5 ms for the Convergecast algorithm and to 52,9 ms respectively, for the Flooding algorithm.

The obtained results show that the algorithm that ensures the highest delay level is the Probabilistic Broadcast algorithm. This was to be expected, since when a node wishes to send a message, it sends it to a randomly selected set of nodes through the broadcast mechanism. In turn, the nodes receiving the message further broadcast it to another set of random nodes.

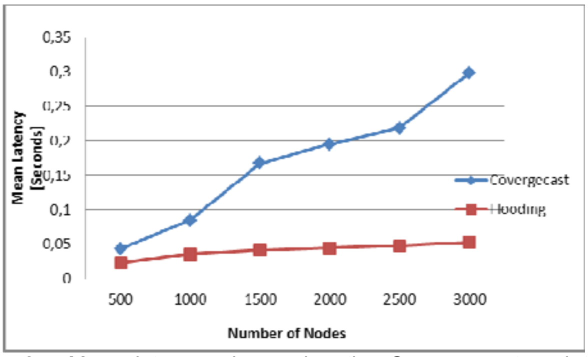

Fig. 8. Mean latency when using the Convergecast and the Flooding algorithms.

The highest performance level in terms of the latency parameter is ensured by the Flooding routing algorithm, followed by the Convergecast algorithm. Thus, as far as the latency is concerned, the Flooding routing algorithm is recommended as part of the Smart City concept. In Fig. 9, note the progress of the number of received packets as the number of WSN nodes increases in a metropolitan network when using the Convergecast routing algorithm.

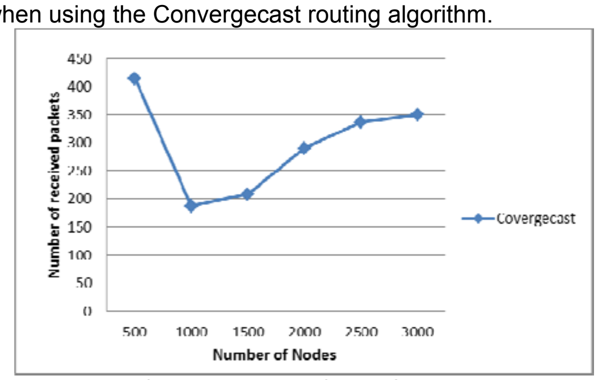

Fig. 9. Number of received packets for the Convergecast algorithm.

Fig. 10 presents the number of received packets for the Probabilistic Broadcast and Flooding algorithms. As has been presented in the previous section, the Convergecast algorithm provides the highest number of received packets as it uses a many-to-one communication mechanism. Thus, in a simulation scenario, each node sends a packet to the coordinating node every 30 seconds. Since in the first case, the 500 nodes are scattered on a smaller geographical area, the number of received packets is maximum, as there are several nodes that can directly send messages to the coordinating node.

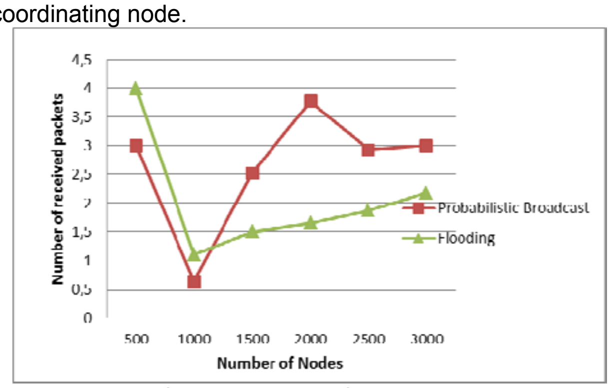

Fig. 10. Number of received packets for the Probabilistic Broadcast and Flooding algorithms

The obtained results show that the maximum number of received packets is provided by the Convergecast algorithm, followed by the Probabilistic Broadcast and Flooding algorithms.

Fig. 11 presents the average number of hops when the Probabilistic Broadcast, Flooding and Convergecast algorithms are used. The obtained results show that the minimum number of hops is ensured by the Flooding algorithm.

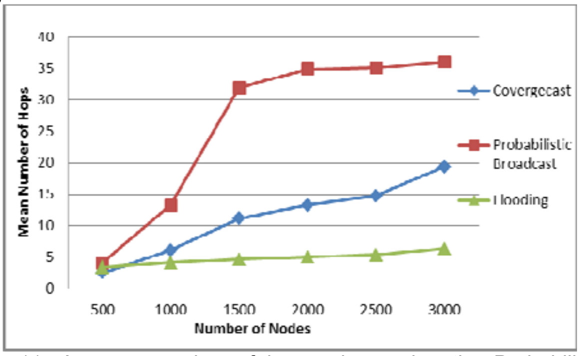

Fig. 11. Average number of hops when using the Probabilistic Broadcast, Flooding and Covergecast algorithms

Conclusions

Our findings show that, in terms of the mean latency parameter, the highest performance level is ensured by the Flooding routing algorithm, followed by the Convergecast and Probabilistic Broadcast algorithms. As far as the number of packets sent, the highest throughput is ensured by the Convergecast routing algorithm as it uses the many-to-one communication mechanism. In terms of performance, the Convergecast algorithm is followed by the Probabilistic Broadcast and Flooding algorithms. When the architecture of the WSN network used in a Smart City concept only has one central point that collects the information, i.e. one sink node, the employment of the Convergecast algorithm is recommended. Another parameter under analysis was the average number of hops made by a packet before reaching its destination. The research findings show that the highest performance level is ensured by the Flooding algorithm, followed by the Convergecast and the Probabilistic Broadcast algorithms. When the application integrated in the Smart City concept is time sensitive, and the related power consumption of the routing process must be as low as possible, since the routing mechanism is other than many-to-one, the use of the Flooding routing algorithm is recommended. However, if the application integrated in the Smart City concept must ensure the highest throughput, while the power consumption is not a priority, the recommended routing algorithm is the Flooding type.

To conclude with, when Smart City concept related WSN applications are implemented and developed, one should take several aspects into consideration. First of all, the topology of the WSN network architecture must be analysed and the number of FFD (Full Function Device) and RFD (Reduced Function Device) nodes must be defined. Secondly, one should also analyse the communication mechanism used in the one-to-many/many-to-one or unicast architecture. Another aspect that should not be neglected is the density of the nodes in the geographical area where the nodes are located, as well as the energy consumption parameters of the WSN nodes. After defining these characteristics, one can select the routing algorithm that would ensure the highest performance level.

Acknowledgment

This paper has been financially supported within the project entitled ***„SOCERT. Knowledge society, dynamism through research”****, contract number POSDRU/159/1.5/S/132406. This project is co-financed by European Social Fund through Sectoral Operational Programme for Human Resources Development 2007-2013.* ***Investing in people!***

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