A Grid-Based Approach to Prolong Lifetime of WSNs Using Fuzzy Logic

Ajai Kumar Mishra, Rakesh Kumar, Vimal Kumar and Jitendra Singh

Abstract Wireless sensor networks (WSNs) are autonomous, self-configured and consist of distributed sensors for monitoring any physical or environmental conditions. Sensor nodes cooperatively disseminate their data through the network to a base station. In recent years, such networks have shown its wide applicability in various areas. Generally, sensor nodes are small, cost-effective, memory constrained and having limited processing capabilities for sensing data in any particular region from the environment. Energy is one of the significant factors in such network. Whole network lifetime depends on how efficiently consumption of energy takes place. Sensor nodes are combined into groups which is called cluster. The purpose of clustering approach is to make the consumption of energy in more effective way. A cluster head node is used for collecting sensed data from cluster nodes for transmitting to the base station. An efficient election of cluster head minimizes energy consumption, thereby increasing network lifetime. One major drawback in dynamic clustering approach is that in every round, cluster head selection is done locally and decides the cluster region. This process has extra communication cost in massage exchange to select the appropriate cluster head. Transmission of message from one node to another node consumes energy that leads to inefficient use of energy resource. In this paper, a non-probabilistic grid-based approach to prolong the WSNs lifetime using fuzzy logic has been proposed. In this, whole network is divided into predefined grid area and selecting a node as grid head (GH) using two fuzzy variables, viz., base station distance and residual energy of sensor nodes. This approach uses a multi-hop communication

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S.K. Sahana and S.K. Saha (eds.), *Advances in Computational Intelligence*,
Advances in Intelligent Systems and Computing 509,
DOI 10.1007/978-981-10-2525-9_2

approach. GH nodes are authorized to communicate with other GH nodes and base station. Simulation results show that the proposed approach prolongs WSNs network lifetime than existing ones.

Keywords Grid Head • Fuzzy logic • Non-probabilistic • Wireless sensor networks

1 Introduction

Recent advancement in microelectromechanical system (MEMS) has made availability of cheaper small wireless sensor nodes feasible nowadays. Normally, WSNs are deployed for specific purposes. Such networks consist of wireless nodes, which have scarce resources in terms of energy, memory, and computational power. Sensor nodes use radio frequency (RF) for communication purpose. A sensor node consists of five units, viz., transceiver, sensor, processor, memory, and a power unit. Figure 1 shows architecture of a wireless sensor node.

Most important unit in all five units defined above is power unit, because wireless sensor network lifetime completely depends on power source. Sensor nodes used in wireless sensor network are battery operated which is non-rechargeable in nature and replacement of batteries is not feasible [1]. Whole network lifetime depends mostly on sensor nodes power source. An efficient use of clustering technique minimizes sensor nodes energy consumption. In this technique, only some nodes allowed to communicate with a base station [2–4]. Nodes have this characteristic called cluster head (CH). Controlling and managing energy consumption in an efficient way are a major challenge in WSNs. Data communication process is more energy consuming with respect to data processing at nodes. Energy consumption may be minimized by making efficient communication between nodes. To execute three thousands instructions, energy consumption is equivalent to one bit data transmission at one hundred meters [5]. A cluster head is accountable for gathering data from other member nodes of a cluster and sending

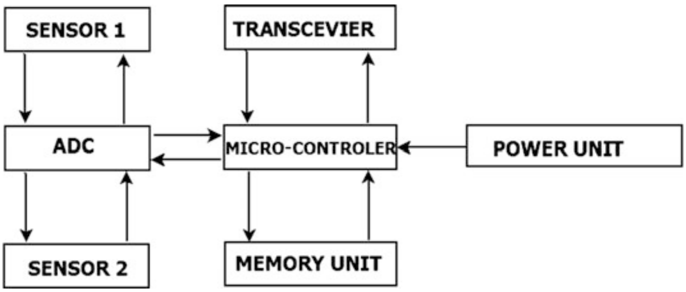

Fig. 1 Architecture of sensor node

processed data to a base station using aggregation mechanism [6]. An efficient election of cluster head (CH) can significantly minimize energy consumption, thereby increasing network lifetime. Uncertainties in WSNs can be handled by the use of fuzzy logic. Zedah et al. [3] in their study demonstrated that algorithms based on probabilistic theory are less appropriate than fuzzy-based algorithms.

From soft computing domain, fuzzy logic is one of the most widely used problem-solving methodologies used in control system. It provides a quicker approach to reach at a definite conclusion in a scenario with incomplete and non-numerical noisy information. It exhibits human intelligence reasoning behavior to handle incomplete data and unexpected situation. For wireless sensor network protocol design, fuzzy logic exhibits advantages in terms of transmission media characteristics and protocol performance making easy fuzzy representation and realistic. It can handle various wireless sensor networks uncertainties in an efficient manner. LEACH is the main protocol for clustering algorithms in wireless sensor networks. The cluster head selection is based on probabilistic approaches [3, 7, 8], and local information is used to make decision for cluster formation. Research activities are being carried out to overcome WSNs constraints and solve application and design issues.

Various centralized and distributed have developed to select cluster head and to form clusters. When network size increases, centralized schemes are not suitable. For large-scale networks, distributed schemes are more suitable. In distributed schemes, nodes within a cluster locally decide its cluster head and its cluster members on the basis of various parameters. Clustering protocol may be dynamic and static. In dynamic clustering [2, 7, 8, 9, 10, 11] protocol, operation has various rounds, and cluster is formed in each round. Because of this, energy depletion rate is high. Many clustering algorithms [2, 12, 13, 14, 15, 16] based on fuzzy logic that is useful for taking real-time decisions without exact information of system.

This paper proposes a grid-based approach to prolong WSNs lifetime. Grid head selection approach using fuzzy logic is non-probabilistic and fully distributed. Distributed grid head selection fixed routing scheme reduces extra communication cost with base station. No randomized function is used to generate a number to make decision to select grid head like other probabilistic approaches. Fuzzy logic is used to calculate fitness value for nodes for selecting as grid head. Residual energy of sensor node, distance from base station, is taken as a parameter to compute grid head probability value.

The rest of this paper is organized as follows. Related work, different clustering algorithms for WSN, along with their advantages and disadvantages has been given in Sect. 2. Our proposed scheme is described in Sect. 3. Simulation results and discussions have been presented in Sect. 4. Finally, the paper concludes by giving future scope in Sect. 5.

2 Related Works

LEACH [12] gave a hierarchical protocol for WSN which is one of the most widely used protocols by most of the researchers. In this, sensor nodes transmit to their cluster heads. Each cluster head aggregates and compresses the data, and finally forward this data to a remotely located centralized base station (BS). A stochastic algorithm in each round is used by a sensor node to determine whether it will be elected as a cluster head in each round. LEACH operation is comprised of a number of rounds. In each round, there is a set-up phase where clusters are formed. This is followed by a steady-state phase. In this, data are sent from sensor nodes to the cluster head and finally to the base station (BS). Clusters formation in LEACH is done by the use of a distributed algorithm. In this algorithm, sensor nodes make self-decisions without any centralized controlling authority. At the beginning of round r + 1, which starts at time t with probability P_i (t), each sensor node i elects itself as a cluster head. Selection of P_i (t) is made in such a manner that the expected number of cluster heads for this particular round is k. If there are N sensor nodes in a network, then the probability of becoming a cluster head by each node at the end of round r is given by the following equation:

$$P_i(t) = \begin{cases} \frac{k}{N - k^*(r \bmod N/k)} : & C_i(t) = 1 \\ 0 & C_i(t) = 0 \end{cases} \tag{1}$$

where

$C_i(t) \leftarrow$ indicator function to determining a sensor node i has been a cluster node within the most recent (r mod N/k) rounds.

$C_i(t) = 0$ implies sensor node i as a cluster head. In this way, only nodes that have not already been elected as cluster head recently (i.e., C_i $(t) = 1$), and may be elected as cluster head in the next round, i.e., $r + 1$. If p represents probability factor, then by replacing k/N in Eq. (1) as p, we obtain a threshold value. This can be further used as a threshold value to select a node as a cluster head. Each sensor node chooses a random number between 0 and 1. If this number is less than a threshold value $T(n)$, then node is elected as a cluster head for the present round. The threshold value can be computed by the following equation:

$$T(n) = \begin{cases} \frac{P}{1 - p^*(r \bmod 1/p)} & if\ n \in G \\ 0 & \text{otherwise} \end{cases} \tag{2}$$

where

G $\leftarrow$ set of sensor nodes not been cluster head in the last $1/p$ rounds.

The major drawback of LEACH protocol is poor clustering formation. In this, some cluster heads are very close to the base station, while some others are very far away. Thereby, depletion of residual energy of cluster heads far away leads at a faster pace than the closer ones.

Gupta et al. [17] introduced fuzzy logic in wireless sensor networks. Fuzzy LEACH is derived from the LEACH base protocol. As per Eq. 2, cluster heads selection is done using a threshold value in the LEACH protocol which is fixed. To overcome the issue of poor clustering in LEACH, fuzzy logic plays a vital role in cluster head election mechanism, and it overcomes the problem encountered by pure probabilistic models. In Fuzzy–LEACH, three fuzzy descriptors are used, viz.,

- energy of node
- concentration and
- node centrality

They enhance process of cluster head election. Node centrality value reflects how central the node is to the cluster. This is computed using sum of the squared distance of other sensor nodes from a predefined sensor node. A base station performs the election of cluster head in each round for every sensor node to become a cluster head by examining three input fuzzy variable in F-LEACH. Twenty-seven fuzzy IF–THEN rules are predefined at the base station. F-LEACH assumes that the base station generates an appropriate cluster head as the base station has full information about the entire network. Each node of a cluster sends k bit message to the cluster head. The cluster head receives and processes it into *cnk* bit messages. The value $c \leq 1$ is known as compression coefficient. F-LEACH working model is almost similar as LEACH. In F-LEACH, two phases are required for the cluster head selection. Each one consists of a setup phase and followed by a steady state. Cluster heads are elected during setup phase using fuzzy logic knowledge processing, whereas various data processing is performed during steady-state phase.

Kim et al. [18] first gave a mechanism for the election of cluster head using two fuzzy variables as input, viz., energy and proximity distance. The election of cluster head by the use of fuzzy logic (CHEF) is given by proximity distance. It is defined as the summation of distances between the cluster head and sensor nodes inside radius (r) distance. In Eq. (3), r refers to the average radius of cluster. It is given as:

$$r = \sqrt{\frac{\text{area}}{\pi . n . P}} \tag{3}$$

where

$n \leftarrow$ number of sensor nodes in WSN.

$P \leftarrow$ battery level.

This approach elects a sensor node with highest energy level as a cluster head. In CHEF [18], two factors, viz., energy and local distance, are used to choose the suitable cluster heads thereby maximizing WSN lifetime. CHEF uses candidate method to take care of more cluster heads formation within r. This approach based on totally probabilistic model for selection of cluster head. Therefore, there is a chance that distribution of CH is not perfect and some node may not have any cluster head.

After making some enhancement in CHEF [18], Sharma et al. [14] proposed a novel fuzzy-based master cluster head election leach which is called F-MCHEL.

The election of cluster head is done in some different ways. Only one cluster head elects as a master cluster head having highest residual energy, instead of directly transmitting from a number of cluster heads to the base station. The approach makes use of two input parameters for FIS, i.e., fuzzy inference system. These are proximity distance and energy to the election of cluster head out of all selected cluster head.

3 Proposed Work

The idea of proposed scheme is initiated by merit and demerit of above discussed approaches. In all previous dynamic clustering schemes, we have two major demerits.

- Decide the cluster area by chosen cluster head in each round.

This process consumes valuable energy resource in processing and communicating among node to fix cluster head and cluster region.

- Overlapping of cluster head range.

It may possible that two nodes chosen as cluster head, close with each other. In our proposed approach, we have made an effort to eliminate these two shortcomings of existing schemes by proposing a novel grid-based dynamic cluster head selection scheme in WSN.

In our proposed approach, as shown in Fig. 2, network area is divided into grids where wireless sensor nodes are randomly deployed. The advantage of doing such kind of arrangement is that all sensor nodes have unique grid, which means that there will be no sensor nodes which belong to more than one grid. It reduces the energy consumption taken place at the time of dynamic clustering approach. In proposed approach, each grid contains almost equal number of homogeneous wireless sensor nodes, but we may also use this approach where each grid contains different numbers of wireless sensor nodes with heterogeneous nature of nodes. Fuzzy system rules used in the proposed model is given in Table 1.

3.1 Steps in Proposed Approach

Pseudocode of the proposed approach is given below.

Step 1: Consider network area n $\times$ n meters
Step 2: Divide network area into small size area (*kxl* in meters) called as grid
Step 3: Randomly deployed sensor nodes each predefined grid
Step 4: For each round $r = 1$ to r_max

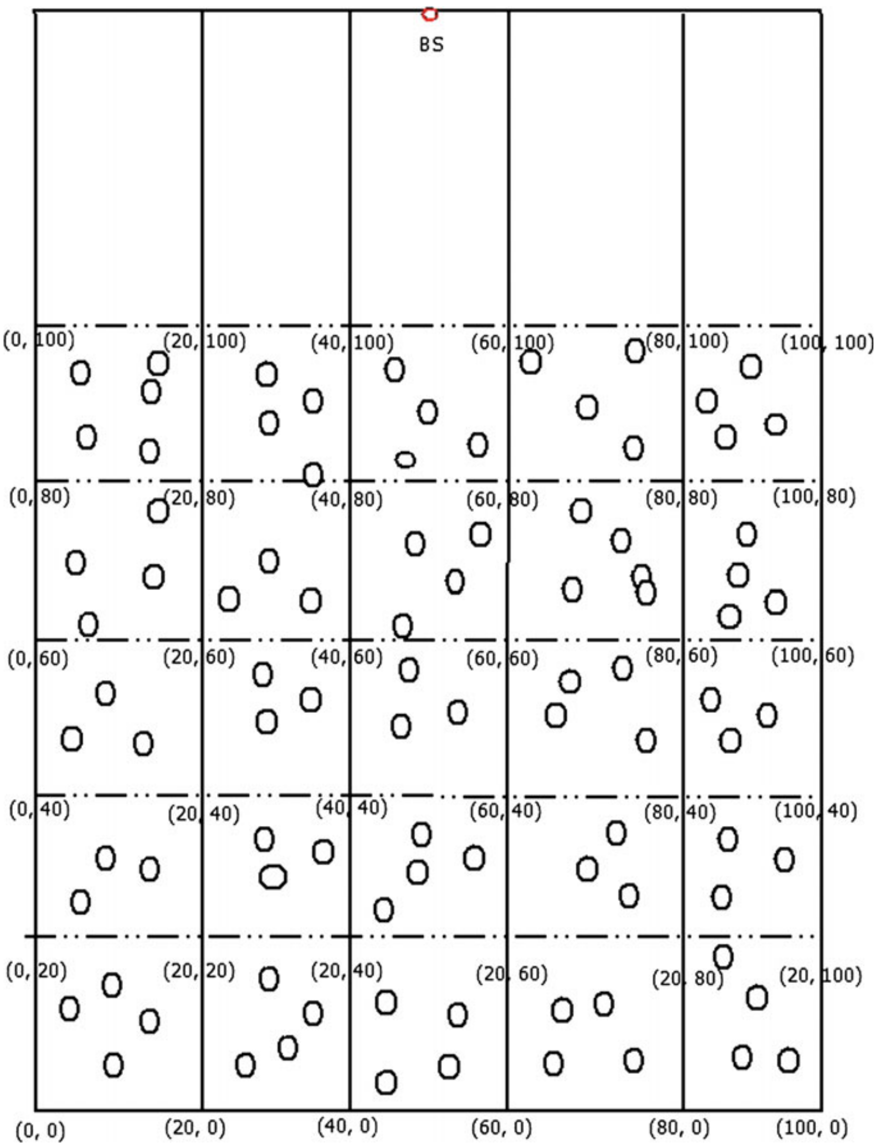

Fig. 2 Model of deployed nodes and base station

Calculate grid head chance of each node using fuzzy variables node residual energy and base station distance.

Step 5: Node having the maximum grid head chance selected as grid head
Step 6: Grid head receives data and forwards to next appropriate grid head or base station
Step 7: Go to step 4 until last node died

Table 1 Fuzzy system rule base

S. No	Base station distance	Residual energy	Grid head chance
1.	Close	Low	Low high
2.	Close	Medium	High
3.	Close	High	Very high
4.	Medium	Low	Rather medium
5.	Medium	Medium	Medium
6.	Medium	High	Low medium
7.	High	Low	Very low
8.	High	Medium	Low
9.	High	High	Rather low

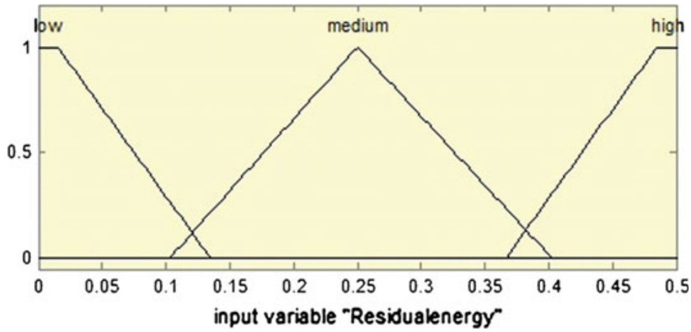

Fig. 3 Membership function for residual energy

3.2 Input and Output for Fuzzy System

Grid head chance calculation of each node of network is based on two fuzzy variables, and output is calculated based on the defuzzification method.

3.2.1 Input Variables

Residual Energy: Residual energy is calculated as remaining energy of sensor nodes till current round. In self-organization scheme, cluster head consumes much power than member nodes, because it has responsibility of data aggregation, processing of data, routing of data, etc. Membership function for residual energy is shown in Fig. 3.

Residual Energy of sensor node = Initial Energy of sensor node – consumed energy till current round.

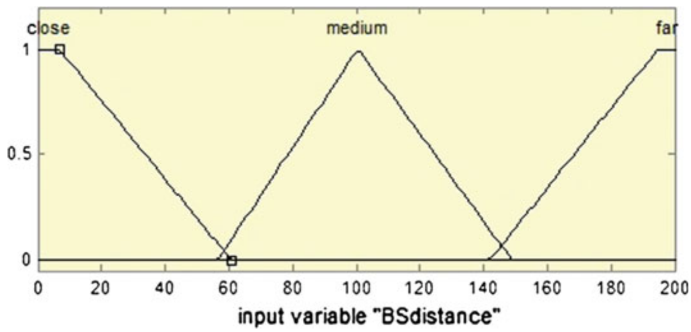

Fig. 4 Membership function for base station distance

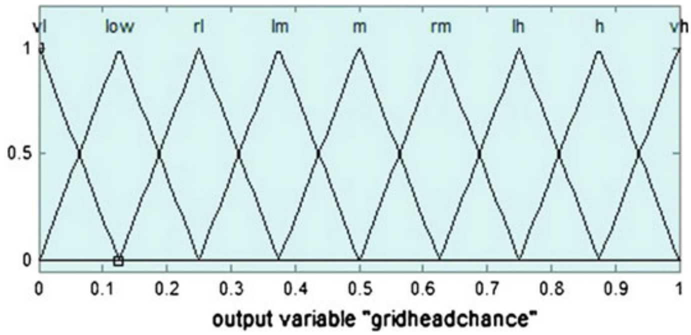

Fig. 5 Membership function for grid head chance vl = Very low, rl = Rather low, lm = Low medium, m = Medium, rm = Rather medium, lh = Low high, vh = Very high

Base Station Distance: Distance of grid head from base station. It is calculated using the distance square method. Membership function for base station distance is shown in Fig. 4.

3.2.2 Output

Output produced by fuzzy system must be crisp for real time implementation. In fuzzy inference system, we apply fuzzified value as input but output must be defuzzified value. In this approach, we use centroid method of defuzzifiation to get crisp output for selection of grid head. Membership function for grid head chance is shown in Fig. 5.

4 Simulation and Result Analysis

Proposed approach is simulated using the MATLAB simulation environment. The performance of this protocol is compared with the low energy adaptive clustering hierarchy, i.e., LEACH. The results show that the proposed approach, i.e., GAPFL extends the network lifetime, reduces the energy consumption requirement, and optimizes the number of cluster heads. Table 2 contains the simulation parameters.

Table 2 Simulation parameters

Parameter	Value
Network size	100 m * 100 m
Base station location	50 m, 140 m
Sensor nodes	200
Initial energy of nodes (E_0)	0.5 J
Packet size	4000 bit
Transmission energy (E_{TX})	50 nJ/bit
Receiving energy (E_{RX})	50 nJ/bit
E_{fs}	10 pJ/bit/m^2
E_{amp}	0.0013 pJ/bit/m^4

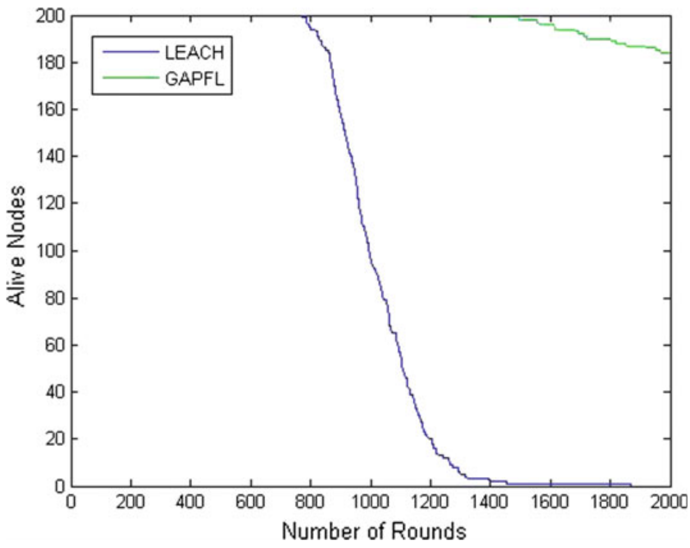

Fig. 6 Number of alive nodes in GAPFL versus LEACH

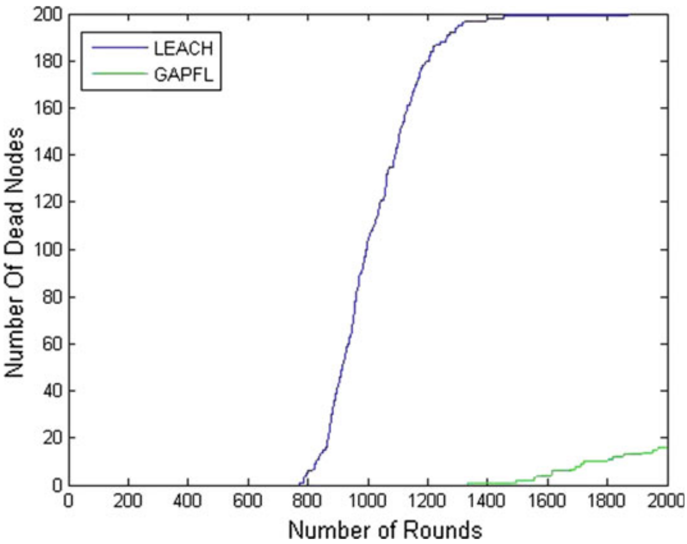

Fig. 7 Number of dead nodes in GAPFL versus LEACH

4.1 Simulation Results

MATLAB [17] tool is used to get the simulation results, as shown in Figs. 6 and 7. GAPFL protocol prolongs WSNs lifetime in terms on number of rounds. We simulated and compare GAPFL with LEACH in various number of rounds. Simulation result is shown below.

The above graph represents number of alive nodes in LEACH. In the above graph, till 2000 rounds, no nodes alive in LEACH protocol but using proposed, i.e., GAPFL approach near about 182 nodes is still alive.

5 Conclusion and Future Scope

In this paper, we proposed a grid-based approach to prolong wireless sensor networks lifetime using fuzzy logic which resolves the issues related with probabilistic approaches. Presented scheme is fully non-probabilistic, no random () function is used like CHEF [18]. In our approach, grid head selection is completely deterministic and decided by two variables, viz., base station distance and node residual energy using fuzzy logic. Grid head selection approach is based on nine if–then rules. The use of grid-based approach and fixed routing scheme results in reduction of power consumption in extra transmission and processing of data. Our main contribution in this paper is to reduce number of unnecessary communication and processing of data to prolong wireless sensor networks lifetime. Simulation results show that proposed scheme is helpful to maximize the lifetime of such networks.

Future research issues in our proposed approach will be dynamic grid formation and on demand grid head selection instead of grid head selection in each round. There are also scope for applying artificial intelligence concepts to find grid head and routing in wireless sensor networks.

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http://www.springer.com/978-981-10-2524-2

Advances in Computational Intelligence
Proceedings of International Conference on Computational Intelligence 2015
Sahana, S.K.; Saha, S.K. (Eds.)
2017, XIII, 450 p. 212 illus., 140 illus. in color., Hardcover
ISBN: 978-981-10-2524-2