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Procedia Computer Science 37 (2014) 236 – 243

Procedia
Computer Science

The 5th International Conference on Emerging Ubiquitous Systems and Pervasive Networks (EUSPN-2014)

Hop Adjusted Multi-chain Routing for Energy Efficiency in Wireless Sensor Networks

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Abstract

This paper presents two new chain formation based routing protocols: Multi Chain Energy Efficient Greedy (MCEEG) routing and Hop Adjusted MCEEG (HA-MCEEG). The MCEEG protocol divides network area into rectangular subareas of equal size, such that each one contains equal number of randomly deployed nodes. In each rectangular subarea, minimum distance based next hop (Greedy algorithm) for data transmission is used and the sojourn locations are adjusted in a way that, at a time when data reaches to the terminator node, BS moves to sojourn location in that rectangular subregion. Thus, data is transmitted through shorter parallel routes instead of single lengthy route. HA-MCEEG protocol exploits the radio parameters for energy efficiency i.e., closely inspects the energy costs (transmission, reception, aggregation and amplification), avoids unnecessary data hopping and selects route with minimum energy cost. Simulation results show that the newly proposed protocols perform better than the selected existing protocol in terms of stability period, network lifetime, packet sending rate and scalability.
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Peer-review under responsibility of the Program Chairs of EUSPN-2014 and ICTH 2014.
Keywords: Chain Formation; Energy Efficiency; Routing Protocols; Wireless Sensor Networks, Scalability

1. Background

The spatially distributed autonomous wireless sensors (nodes) along with BS(s) form cooperative network called WSN[1]. Nodes wirelessly communicate and send the gathered information to BS[2]. Regarding power, BS is un constrained; whereas, nodes are constrained[3]. Applications of WSNs include security, pollution monitoring, home automation, body area networks, etc[4].

The latest research in WSNs deals with low power communications, and routing protocols play a key role for efficient energy consumption. Routing begins at neighbour discovery[5]. The need of a specific route with minimum

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Peer-review under responsibility of the Program Chairs of EUSPN-2014 and ICTH 2014.
doi:10.1016/j.procs.2014.08.035

energy cost necessitates the invention of new solutions. Earlier routing techniques, like Direct Communication (DC) and Minimum Transmission Energy (MTE)[6], are not as energy-efficient as at-hand chain formation techniques are. In DC, the battery power of farthest nodes is drained out quickly, whereas in MTE, nearest nodes are mostly penalized.

At present, communication in WSNs is mostly done via two techniques; clustering and chain based. In clustering, CHs are selected by nodes. Individual nodes send sensed data to corresponding CH which transmits the aggregated data to BS[7 8]. On the other hand, chain is formed by establishing a series of connected links among nodes. Each chain has: a starting node (from where chain initiates), a leader node (responsible for data transmission to BS), and an end point (usually BS). PEGASIS[9], one of the popular chain formation based routing protocols, builds greedy algorithm based chain. However, single chain formation between nodes increases the communication which leads to unbalanced energy consumption[10]. Cluster Based Energy Efficient Routing Protocol (CBERP)[11] combines clustering technique of LEACH, chain formation technique of PEGASIS, and cluster organization technique of LEACH-C. Each header node sends data to BS through a chain. In this way, energy consumption of PEGASIS protocol is minimized by CBERP. Chain Cluster based Mixed routing (CCM) protocol[12] uses a hybrid approach of LEACH and PEGASIS. Network field is divided into a number of chains and in each chain, sensor nodes send sensed data to respective chain head. Then, the chain head nodes form a cluster in which CH is responsible for data transmission to BS. Chain-Chain Based Routing Protocol (CCBRP)[13] uses a multi chain approach. In each chain, nodes transmit locally sensed data to their chain leader nodes (primary level). Then, all chain leader nodes form another chain using greedy algorithm. Leader node (secondary level), randomly chosen by all leader nodes, compresses received data along with its own sensed data and sends it to BS.

2. The proposed MCEEG protocol

In subject to energy efficiency, the newly proposed MCEEG protocol divides the entire network area into smaller sub regions; greedy algorithm is independently implemented in each sub region. The benefit of this methodology is data transmission from source to destination through shorter parallel routes which is converse to the lengthy route of single chain PEGASIS. For further energy efficiency improvement, we exploit the un-constrained nature of BS (in terms of energy resource(s)) by using mobile BS instead of the fixed one. This approach also reduces the communication distance between the terminator nodes and BS, ultimately saving terminator nodes' energy. Detailed description of the proposed protocol is in the upcoming subsections.

2.1. Regions formation

The core process of MCEEG protocol is its independent multi-chain formation. So, we assume a square shaped network area and divide it into s equal area rectangular regions (in each sub region an independent chain is established), resulting in multi-chain formation which reduces path for data transmission. Coordinates of the rectangular regions, via this adaptive approach, are calculated as follows.

Let x_{min} is the minimum x-dimension of network area, y_{min} is the minimum y-dimension of network area, x_{max} is the maximum x-dimension of network area, y_{max} is the maximum y-dimension of network area, and x is the difference factor ($x = x_{max}/s$). Then left sided coordinates of rectangular regions are,

$$LC_i = (x_{min}, sx) \tag{1}$$

Similarly, right sided coordinates of rectangular regions are,

$$RC_i = (x_{max}, sx) \tag{2}$$

where, i takes integer values from $[1, ..., n]$.

2.2. Deployment of nodes

The deployment strategy of nodes as well as the number of nodes, vary from application to application. In general, there are two fundamental ways of nodes' deployment; deterministic and random[14]. In the leading strategy, positions of nodes are chosen to minimize the number of nodes required for the desired goal. However, this strategy is time consuming and sometimes impractical in applications like battle field monitoring. The lagging strategy is sometimes more practical in such applications because it is less time consuming. However, requirement of large number of nodes is the in built deficiency, if the lagging strategy is adopted. So, there is a tradeoff between the consumed time and the number of nodes needed. We overcome this tradeoff by deploying nodes in a uniform random manner. In each rectangular sub region, the number of deployed nodes are equal in number (uniform) however their locations are chosen at random. So, '$c = N/s$' number of nodes are randomly deployed in each rectangular sub region such that the nodes of different regions are independent in terms of neighbour(s) discovery (where, N=total number of nodes).

2.3. Determination of sojourn locations

We use mobile BS because it provides energy efficient direct data collection in WSNs, where mobile BS directly collects data from nodes at sojourn locations during the sojourn interval (stay time at sojourn location) as shown in figs. 1(a, b) Sojourn location is the location at which the mobile BS stops for data receptions from a particular sub region. This technique reduces the communication distance between the BS and the terminator nodes, thus minimizing terminator nodes' energy consumption. Number of sojourn locations, 'b', for current round depends upon s such that, $b = s$. Let, b_i be the sojourn location at time t_i. Then,

$$b_i = (x_{min}, ix - 10) \tag{3}$$

where, i takes integer values from 1 to n (i.e., $[1, ..., n]$). To minimize communication distance between BS and nodes, mobile BS is used which results in prolongation of stability period and lifetime of the network.

2.4. Chain formation

In each region, only one chain is formed for the current round. At first, BS selects Initiator Node (IN), which is far from it (i.e., the most distant node from b_i in that region). Then, Nearest neighbour of IN is selected as Next Hop Node (NHN) by BS, and the coordinates of the NHN are saved in a variable called Previous Hop Node (PHN). Again nearest neighbour of PHN is selected as NHN by BS, and the coordinates of the NHN are saved in PHN. The process continues till the closest node to BS is reached. On coordinate basis; the most close node is selected as Terminator Node (TN) by BS, which communicates directly with BS.

Prior to chain formation, BS conducts eligibility test to assure that only alive nodes are engaged in the formation of chain(s). For this purpose, BS checks the energy of each node such that for chain formation it only considers node(s) with residual energy(ies) greater than zero. Number of chains formed depends upon s. Let, c be the number of chains formed. Then, $c = s$. Fig. 1(a) shows regions formed ($x_{max} = 100m$, $y_{max} = 100m$, $s = 5$ and $N = 100$), nodes deployment, and route selection in each region.

2.5. Protocol operation

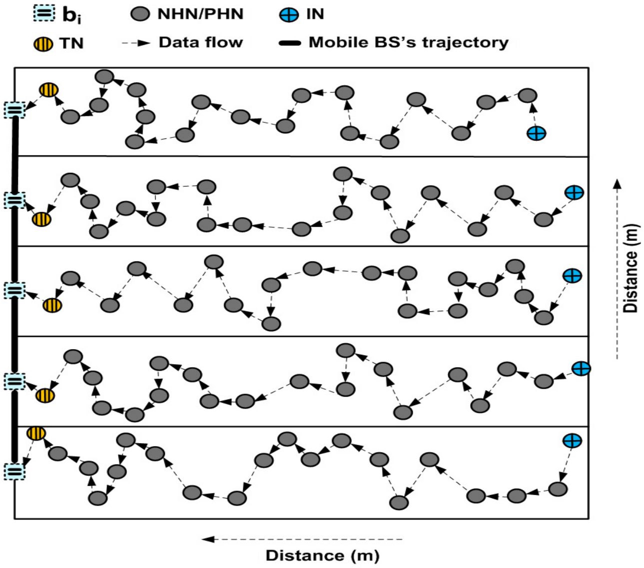
MCEEG's operation from network establishment to data transmission is divided into two phases; setup and steady state.

2.5.1. Setup phase

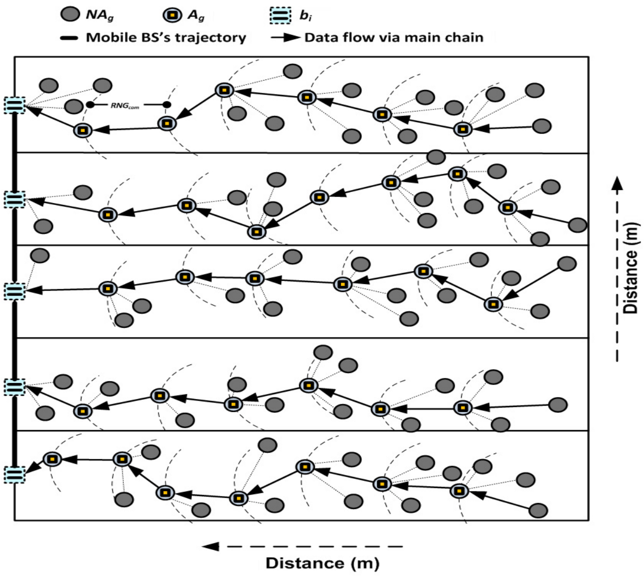
During setup phase, preliminary activities to data transmission like regions formations, determination of sojourn locations, and chain formation are carried out. So, initially equal numbers of nodes are randomly deployed in each region of the network field. Moreover, global knowledge rests with BS, such that it divides the entire network field into equal area rectangular regions on coordinate basis. In each region, one chain is formed in a current round which establishes data transmission path among IN, NHNs, PHNs, TN, and BS.

2.5.2. Steady state phase

Once the platform is established during setup phase, data transmission(s)/reception(s) is(are) accomplished during steady state phase. IN sends its data to NHN in its allocated time slot (TDMA approach) and then it acts as PHN.



(a) MCEEG protocol



(b) HA-MCEEG protocol

Fig. 1. Nodes' deployment and establishment of chains

PHN compresses its own sensed data and received data from IN, and sends compressed data to the next NHN. This process continues till TN receives data which forwards these data to BS.

To improve energy efficiency, each node uses power control mechanism to adjust the transmit power level based on the received signal strength of the neighbour node. Furthermore, the TDMA approach is an efficient use of bandwidth and corresponds low-latency along with energy-efficiency.

3. Extending MCEEG; HA-MCEEG protocol

The proposed MCEEG protocol earns credit by implementing multi-chain approach and BS mobility at sojourn locations in specific time slots, which result in extension of stability period and lifetime of the network. Different paths for data transmission are beneficial. However, (i) in multi-hop communication; energy consumption, data reception, and data aggregation are big factors as compared to transmission distance, and (ii) MCEEG protocol uses unnecessary hops, which minimizes its stability period and network lifetime. So, we propose HA-MCEEG protocol which introduces range for every sensor node as a tool to minimize the number of hops. As a result, stability period and lifetime of the network improve. HA-MCEEG follows the same technique of regions formation as in MCEEG, deployment of nodes, and determination of sojourn locations. Therefore, we begin in the upcoming subsections with chain formation.

3.1. Chain formation

Once the regions are formed and nodes are randomly deployed, the BS takes measures for the establishment of independent chain(s) in each sub region. At first, BS selects node at maximum distance from b_i in that region as IN and calculates distances of all other nodes from it. Then, it sets communication range for all nodes (50m). After this, Aggregator node (A_g *node*) is selected; node at maximum distance within the communication range of IN towards BS. Similarly, the next (A_g *node*) is found at maximum distance within the communication range of the previous A_g *node*. The process continues till BS selects node, which is in the communication range of A_g *node* and in whose communication range is BS. Mark the node in previous step as TN with the capability to communicate directly with BS. Finally, in forward reference of position towards sojourn location, connect non-aggregator nodes (NA_g *nodes*) to already selected A_g *node*.

Before chain formation, BS carries out eligibility test to ensure the engagement of only alive node while forming independent chain(s). For this purpose, BS checks the energy of each node such that for chain formation it only considers node(s) with residual energy(ies) greater than zero. The number of chains formed is according to eqn. 6. Fig. 1(b) shows nodes deployment and route selection in each region for $x_{max} = 100m$ and $y_{max} = 100m$.

The A_g *nodes* in HA-MCEEG protocol act as local control centers to coordinate the data transmissions within their area of influence (i.e., communication rage). Each A_g *node* sets up a TDMA schedule and transmits it to the corresponding NA_g *nodes*. Nodes, A_g or NA_g, only communicate within the allocated TDMA slots. Thus minimizing the number of collisions among data messages. It also allows the radio transceiver of each NA_g *node* to be turned off all the time except during the transmission time, thus reducing their energy consumption. On the hand, the transceiver of A_g *nodes* is turned on for three occasions; data reception from the backward located neighbouring A_g *node*, data reception from the corresponding NA_g *nodes* and data transmission to the forward located A_g *node*.

3.2. Protocol operation

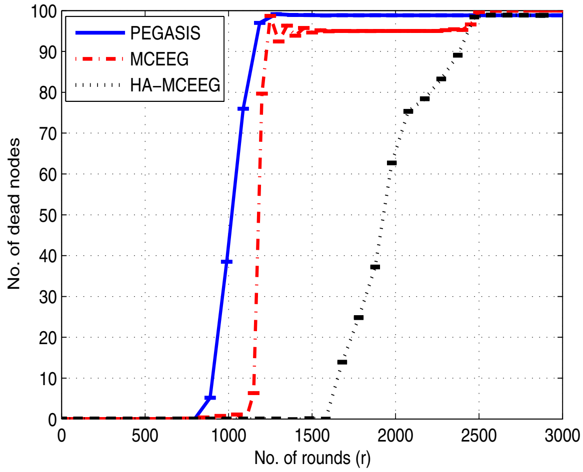
HA-MCEEG's protocol operation from network establishment to data transmission; setup phase and steady state phase, is as follows.

3.2.1. Setup phase

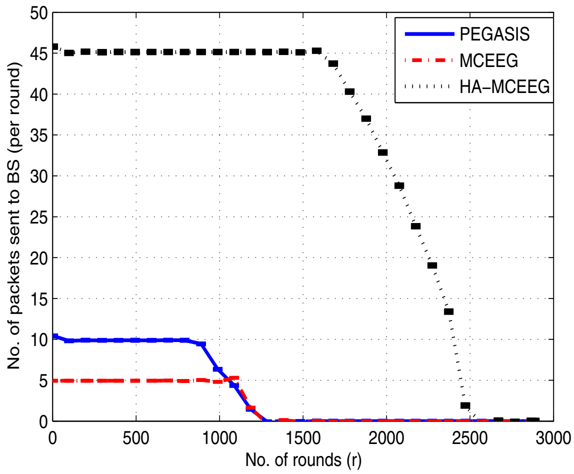
During this phase, it is firstly assumed that BS has global knowledge about the WSN; it logically divides the entire network field into equal area rectangular regions (refer subsection 'regions formation'). The phase then proceeds with the random deployment of equal numbers of nodes in each region of the network field; such that in each region, one chain with minimum number of hops is formed in a current round which establishes path for data transmission among IN, NA_g *nodes*, A_g *nodes*, TN, and BS. Soon after, BS connects disconnected nodes to already established chain or BS in that region, based on maximum distance within communication range.

3.2.2. Steady state phase

All data communication processes i.e., transmission, aggregation and reception follow MCEEG's algorithm.



(a) Rate of dead nodes



(b) Transmitter side: packets sent

Fig. 2. Performance evaluation

4. Simulation Results

Performance of proposed MCEEG and HA-MCEEG protocols is evaluated in MATLAB by comparing them with PEGASIS. Assume a WSN with 100 nodes, equal numbers of nodes are randomly distributed in each region of $100m \times 100m$ network area. BS's positions are according to eqn. 4 and eqn. 5. Initially all nodes are equipped with $0.5J$ energy and $RNG_{com} = 50m$ for each node. We assume collision free wireless channel, therefore effects due to interference in the wireless channel are ignored. Parameters of first order radio model, used in our simulation are; transmitter/receiver electronics energy '$E_{tx} = E_{rx} = 50nJ/bit$', data aggregation energy '$E_{da} = 5nJ/bit/signal$', free space amplifier '$E_{fs} = 0.0013pJ/bit/m^2$', multi-path amplifier '$E_{mp} = 10pJ/bit/m^4$, and packet size '$l = 4000bits$.

In fig. 2(a), there is a comparison of PEGASIS, MCEEG, and HA-MCEEG protocols. MCEEG protocol takes advantage over PEGASIS in terms of the number of rounds from start of the network till the death of first node. MCEEG protocol extends stability period due to multi-chain approach, minimization in communication distance by sending data to nearest neighbour node and BS mobility. Regarding energy consumption, factors like E_{tx}, E_{rx} and

E_{da} have more cost as compared to the distance of communication. HA-MCEEG protocol further extends stability period by reducing the cost of energy consumption. For a given node, HA-MCEEG protocol selects node within its communication range at maximum distance as A_g *node* and this technique ensures the elimination of unnecessary hops. Thus, network's energy is saved or efficiently utilized. According to simulation results shown in fig. 2(a), MCEEG performs 23.54 % better than PEGASIS. HA-MCEEG performs 51.8 % better than PEGASIS, and 32.21 % better than MCEEG.

From round number 1191 to 2447 in fig. 2(a), MCEEG protocol's energy consumption is uniform till the death of 95 nodes. However, after the death of 95 nodes, energy consumption is non-uniform. This is because INs consume E_{tx} only. INs do not consume E_{rx} and E_{da}. HA-MCEEG fixes the problem by reducing the number of hops. Network lifetime of MCEEG is 50.18 % longer than PEGASIS. HA-MCEEG performs 1.72 % better than MCEEG and 51.04 % better than PEGASIS.

Close look at fig. 2(b) shows the number of packets sent to BS in each round. In MCEEG protocol, IN sends data packet to NHNs and PHNs till TN receive data packet. TN compresses received data packets and sends aggregated data to BS like chain leaders of PEGASIS protocol. Due to less number of TNs in MCEEG protocol as compared to chain leaders in PEGASIS, MCEEG protocol sends less number of data packets to BS as compared to PEGASIS. However, according to HA-MCEEG technique, BS receives data packets from nodes whose distance from BS is less than or equal to communication range and the number of such type of nodes in HA-MCEEG protocol is more than MCEEG and PEGASIS protocols. Therefore, HA-MCEEG gets the credit of sending more packets to BS as compared to MCEEG and PEGASIS. Numerically, MCEEG's packets sent to BS are 44.61% less than PEGASIS. HA-MCEEG sends 13.71% more packets to BS than PEGASIS and 52.20% more than MCEEG.

Table 1. Varying network area and no. of nodes (FND=First Node Death, LND=Last Node Death and $|\aleph|$=number of nodes)

Protocol	Network area	$\lvert\aleph\rvert$	FND(r)	LND(r)
PEGASIS	$100m \times 100m$	100	815	1198
	$150m \times 150m$	150	751	1093
	$200m \times 200m$	200	746	1090
MCEEG	$100m \times 100m$	100	1047	2300
	$150m \times 150m$	150	903	1783
	$200m \times 200m$	200	827	1537
HA-MCEEG	$100m \times 100m$	100	1680	2400
	$150m \times 150m$	150	1640	2354
	$200m \times 200m$	200	1627	2346

By setting $RNG_{com} = 50m$ for each node; HA-MCEEG protocol, we vary the network area from $100m \times 100m$ to $200m \times 200m$ and the number of nodes from 100 to 200. Thus, keeping proper aspect ratio (to provide better area coverage). Simulation results for these variations are shown in table 2. From these results, we conclude that among the three protocols; (i) MCEEG protocol exhibits sharp decay in stability period as well as network lifetime, (ii) PEGASIS protocol shows moderate decay in stability period and network lifetime, and (iii) HA-MCEEG protocol exhibits flat decay in stability period as well as in network lifetime, whenever these protocols are subjected to increased network area and number of nodes. These results are obvious because increasing network area and number of nodes; (i) increases the number of hops for data delivery from IN to TN resulting in more E_{da} cost which in turn causes sharp decay for the proposed MCEEG protocol in terms of stability period and network lifetime, (ii) increases the communication distance, however, the effect of communication distance is less than data aggregation, thereby moderate decay in stability period and network lifetime is seen for PEGASIS protocol, and (iii) causes flat decay in stability period and network lifetime for the proposed HA-MCEEG protocol due to minimization of unnecessary hops for delivering data to BS.

5. Conclusion and Future work

In this paper, two new chain formation protocols for WSNs are proposed. Benefits of using multi-chain approach; the MCEEG protocol, are the elimination of long route and transmission of data through a much shorter route. Moreover, mobile BS further enhances its performance. HA-MCEEG protocol inherits some characteristics from MCEEG protocol and focuses on the avoidance of unnecessary hops. Simulation results show that the newly proposed protocols perform better than PEGASIS protocol in terms of stability period, network lifetime, packet sending rate, and scalability. In future, real time experimental test bed development for WSNs is under consideration.

References

1. M. Tahir, N. Javaid, A. Iqbal, Z. A. Khan, N. Alrajeh, "On Adaptive Energy Efficient Transmission in WSNs", International Journal of Distributed Sensor Networks, Volume 2013 (2013), Article ID 923714, pp. 76-79, 2011.
2. X. Liu, "A survey on clustering routing protocols in wireless sensor networks", Sensors, 12(8), 11113-11153.
3. A. M. El-Semary, M. M. Abdel-Azim, "New Trends in Secure Routing Protocols for Wireless Sensor Networks", International Journal of Distributed Sensor Networks, Volume 2013 (2013), Article ID 802526, 16 pages.
4. M. Sunita, J. Malik, S. Mor, "Comprehensive study of applications of Wireless Sensor Networks", International Journal of Advanced Research in Computer Science and Software Engineering, ISSN 2277, 2012.
5. L. Saraswat, S. Kumar, "Resource Biased Routing (RBR) algorithm for energy optimization in Wireless Sensor Networks", Resource 2 (3), 2012.
6. T. Shepard, "A channel access scheme for large dense packet radio networks", ACM SIGCOMM Computer Communication Review, Vol. 26, ACM, 1996, pp. 219230.
7. W. Heinzelman, A. Chandrakasan, H. Balakrishnan, "Energy-efficient communication protocol for wireless microsensor networks", System Sciences, 2000. Proceedings of the 33rd Annual Hawaii International Conference on, IEEE, 2000.
8. S. Muruganathan, D. Ma, R. Bhasin, A. Fapojuwo, "A centralized energy-efficient routing protocol for Wireless Sensor Networks", Communications Magazine, IEEE 43 (3) (2005) S813.
9. S. Lindsey, C. Raghavendra, "PEGASIS: Power-Efcient GAthering in Sensor Information Systems", Aerospace conference proceedings, 2002. IEEE, Vol. 3, IEEE, 2002, pp. 31125.
10. S. J. Lim, MS. Park, "Energy-Efficient Chain Formation Algorithm for Data Gathering in Wireless Sensor Networks," International Journal of Distributed Sensor Networks, 2012.
11. Y. Lee, K. Lee, H. Lee, A. Kusdaryono, "CBERP: Cluster Based Energy efcient Routing Protocol for Wireless Sensor Network", Recent Advances in Networking, Proceeding of the 12th WSEAS International Conference on VLSI and Signal Processing (ICNVS10), Cambridge, UK, 2010, pp. 2428.
12. F. Tang, I. You, S. Guo, M. Guo, Y. Ma, "A chain-cluster based routing algorithm for Wireless Sensor Networks", journal of intelligent manufacturing 23 (4) (2012) 1305.
13. S. Ali, S. Refaay, "Chain-chain based routing protocol", IJCSI International Journal of Computer Science Issues 8.3 (2011), 1694-0814.
14. H. Zhang, J. C. Hou, "Is deterministic deployment worse than random deployment for wireless sensor networks", In INFOCOM, 2006.