

EEC: Evaluation of Energy Consumption in Wireless Sensor Networks

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ABSTRACT

Wireless Sensor Networks (WSN) consists of battery-powered sensor nodes which collect data and route the data to the Base Station. Centralized Cluster-based routing protocols efficiently utilize limited energy of the nodes by selecting Cluster Heads (CHs) in each round. Selection of CHs and Cluster formation is performed by the Base Station. In each round, nodes transmit their location information and their residual energy to the Base Station. This operation is a considerable burden on these resource hungry sensor nodes. In this paper we propose a scheme whereby a small number of High-Energy nodes gather location information and residual energy status of the sensing nodes and transmit to the Base Station. This scheme eliminates CH advertisement phase in order to conserve energy. Based on the energy consumption by various types of nodes, we have derived an energy model, also known as EEC, for our algorithm which depicts the total energy consumption in the network.

Keywords:- Wireless Sensor Network, LEACH, Cluster Head, Base Station.

I. INTRODUCTION

Micro-Electro-Mechanical Systems (MEMS) technology has seen phenomenal growth in recent years which has enabled the deployment of small, battery powered sensor nodes. These tiny sensor nodes have brought a revolution in the world of Wireless Communication System [1]. Sensor nodes are constraint with resources like energy, storage, processing capabilities and available bandwidth. Sensor nodes collaborate with each other to form Wireless Sensor Network (WSN) which outperforms many existing Wired and Wireless technologies in terms of their use. These networks are deployed in environments which cannot be monitored with traditional networks. They have numerous applications like volcanic monitoring, battlefield surveillance, home appliances, industrial monitoring, agriculture, health and many more. These networks possess some unique characteristics like self-healing, self-organizing and fault tolerance. WSN is considered as a next wave of computing. WSN market is expected to grow from its current half a billion dollars to around two billion dollars by 2021 [2]. Sensor nodes are randomly deployed in most applications and left unattended. Hence it becomes necessary that the

energy of the nodes should be utilized efficiently to extend the lifetime of the network. Energy-efficient routes need to be setup and the data should be reliably transferred from the nodes to the Base Station [3]. If all these nodes route their data directly to the Base Station, large amount of energy will be consumed due to long range communication. Hence nodes are grouped together to form Clusters. In Clustering protocols, one node is elected as Cluster Head (CH) which gather, aggregate and route the data to the Base Station [4] These CHs can either transmit the data directly to the Base Station or route their data to the upper level CHs and hence form a hierarchy of Clusters to reach the Base Station.

In existing Clustering Hierarchical protocols, the CH is either selected randomly or this task being performed by Base Station. Base Station uses the residual energy and location information of the nodes as selection criteria. However in this scheme, the nodes have to transmit their location information and energy status at the start of each round to the Base Station. Although, this mechanism results in an optimal number of CHs in

each round but it consumes a considerable amount of energy.

In this paper, we have proposed a centralized solution for CH selection. In our approach, CH selection and Cluster formation are performed by the Base Station. Here, we have considered five percent of the nodes as High-Energy nodes in addition to sensing nodes in any sensor network. As per the above statistics, a network of hundred sensing nodes would require an additional five High-Energy nodes and a network of two hundred sensing nodes would require an additional ten such nodes. The number of such nodes in any network depends on its scalability. These High-Energy nodes transmit the location and residual energy of the sensing nodes to the

Base Station in each round. They are located in the sensor field in order to enable the sensing nodes to minimize their energy consumption during communication. Once they transmit the sensing node's location and energy information to the Base Station, they go to sleep mode till the beginning of next round. The Base Station selects optimal number of CHs.

Also, our proposed algorithm eliminates "CH-Advertisement". CHs are no longer required to advertise themselves to their respective Cluster members. This approach enables the CH nodes to conserve their energy. We have calculated the energy consumption by different nodes in the network and formulated a new energy model. Our model then depicts the total amount of energy consumed in the network.

This paper is organized into six sections. In section II we presented related works and refined our objectives for a new Centralized CH selection and Cluster formation approach. In Section III we presented radio model for sensor nodes of our algorithm. In Section IV we have described the network architecture model and the operations performed by the Base Station for Cluster formation and CH selection. In Section V, we have derived an energy model for our algorithm. We concluded our work in section VI with future directions.

II. RELATED WORKS

A Centralized Low Energy Adaptive Clustering Hierarchy (LEACH-C) protocol was presented in [5]. In this protocol, the Base Station elects the optimal number of Clusters and CHs using simulated annealing algorithm [6]. At the start of each round, the nodes send their remaining energy levels and location information to the Base Station which in turn calculates the average of these residual energy levels. All those nodes whose energy levels are greater than average value are elected as CHs. Practically this approach cannot guarantee the optimal number of CHs. It is highly probable that in each round, there will be a considerable number of CHs exceeding the optimal value. Also, this protocol lacks the detail mechanism of its operation. This protocol is an improvement over LEACH [7], where each node autonomously elects itself as CH. LEACH results in poor Cluster formation and nodes with very low energy are frequently selected as CHs.

Base-Station Controlled Dynamic Clustering Protocol (BCDCP) was proposed in [8]. BCDCP uses the same centralized approach for Cluster formation as of LEACH-C. Additionally, the Base Station maintains a set S , which contains all those nodes whose energy levels are greater than average energy value. The task of the Base Station is to elect an optimal number of Cluster Heads (N_{CH}) from S and arrange all the remaining nodes of the network around them. BCDCP implements an iterative Cluster splitting algorithm which splits the sensor network into two sub-Clusters and proceed further until sufficient numbers of small Clusters are formed. The number of sub-Clusters depends on the number of N_{CH} nodes. BCDCP uses balanced Clustering technique [9] to establish Clusters having approximately equal number of nodes. This protocol consumes a considerable amount of time in Cluster formation and CHs selection and hence does not suit time critical applications.

Base-Station Initiated Dynamic Routing Protocol (BIDRP) is proposed in [10]. All the above protocols emphasis on the homogenous sensor networks where all the nodes have the same initial

energy. BIDRP is specifically used for heterogeneous sensor networks where some nodes have higher energy in the network. These higher energy nodes are always elected as CHs in each round. The Base Station broadcasts a packet which is specifically meant for these higher energy CH nodes which in turn calculate their distance from the Base Station based on the Received Signal Strength (RSS) of the packet. This enables the CHs to adjust their transmission power in order to reach Base Station in one hop. Next, these CHs transmit the same packet to the CHs which are one level higher. They also perform the same function and adjust their transmission power and this process continues till the highest level of CHs. Base Station is at Level 0, the CHs which are one hop away from Base Station are at Level 1 and so on. Cluster Heads aggregate their data from their respective Clustering nodes and deliver it to the CHs which are one-hop up the tree. Data always flow from higher levels to lower level until it is delivered at the Base Station. BIDRP lacks the concept of CH rotation. Same higher energy nodes are used as CHs in each round, ultimately their energy will drain after some time. For video streaming and multimedia applications, this protocol does not produce the best results as these applications have considerable amount of data and require constant availability of services. BIDRP does not provide an alternative solution in situations where these higher energy CH nodes die. Clustering Protocol with Mode Selection (CPMS) is proposed in [11]. This protocol is based on [12-20] for CH selection and on [21-30] for levels formation. CPMS improve the selection of Leader node based on Energy-Distance (E-D) ratio. Residual energy of each CH node is divided by their respective levels to obtain E-D ratio. The one whose E-D ratio is highest is elected as the Leader node which will gather the data from all CHs and transmit to Base Station. The drawback of this approach is that CHs does not rotate like [10,31-37] and CH nodes far away from Base Station have less chance to be elected as Leader nodes. Latest trends in the field can found [38-47].

All these protocols have one major drawback in common: all the nodes transmit their residual energy status to the Base Station at the start of each round which is a considerable burden on these energy-constraint sensor nodes. Alternatively, there

should be additional solution to broadcast energy status of sensor nodes in each round which can minimize the energy consumption. Our algorithm is based on the latter, where a small number of High-Energy nodes perform transmission of location and residual energy information of the sensing nodes to the base station. Base Station evaluates the energy level of all the nodes and calculates an average threshold value. Nodes are selected as Cluster Heads based on their energy values. If their energy level is greater than threshold value, they are eligible to be elected as Cluster Heads [48-51]. More than one node in the same cluster cannot be elected as Cluster Head. Nodes having energy values greater than average threshold energy level are elected as Candidate nodes. The choice of Cluster Head node among the Candidate nodes depends on various factors like the specific number of Candidate nodes in a particular Cluster, Candidate node elected as Cluster Head in previous round, its present energy status.

III. MODEL AND ARCHITECTURE

A. Sensor Node Radio Model

The radio model used by the sensor nodes in our network is shown in Figure 1 and is based on [12-18].

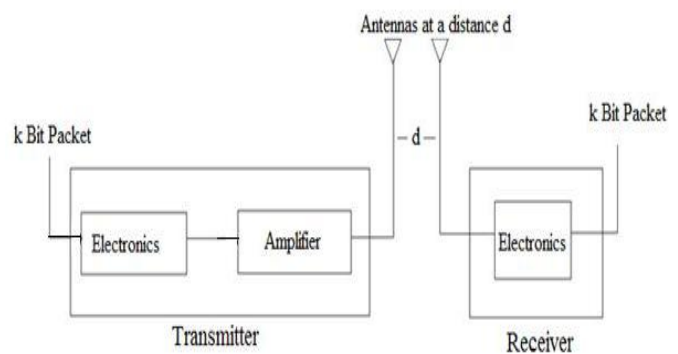


Fig.1. Sensor Node Radio Model

In Figure 1, k is the length of message and d is the distance between the receiver and transmitter nodes. E_{Tx} and E_{Rx} are the energy consumed by the transmitter and receiver nodes respectively. E_{Tx} is equal to the sum of energy dissipated by the Transmitter's electronic (E_{elec}) and its amplifier

(ϵ_{amp}) while E_{Rx} is equal to the energy dissipated by the receiver's electronics (E_{elec}). Their values are given below in the equation 1 and 2 respectively [19-24].

$$E_{Tx}(k, d) = E_{elec} k + \epsilon_{amp} kd^n \quad (1)$$

$$E_{Rx}(k) = E_{elec} k \quad (2)$$

The amount of energy consumed by the transmitter's amplifier depends on the distance (d) between the transmitter and receiver node. If the distance (d) is less than crossover distance ($d_{crossover}$), then path loss (n) is modeled by free space [12]. FS-amp stands for energy consumed by amplifier in free space. The amount of energy consumed by the transmitter in this case is given by equation 3:

$$E_{Tx}(k, d) = E_{elec} (k) + \epsilon_{FS-amp} (k)d^2 \quad (3)$$

If the distance d is greater than or equal to $d_{crossover}$, then Two-Ray model (multipath) is used. Here equation 1 is modified as following:

$$E_{Tx}(k, d) = E_{elec} (k) + \epsilon_{Two-Ray-amp} (k)d^4 \quad (4)$$

In free space, there is a line of sight connection between transmitter and receiver while in Two-Ray ground propagation model, signal travel through multi paths due to deflection through obstacles. The crossover distance is given in equation 5:

$$d_{crossover} = 4\pi\sqrt{L h_t h_r} / \lambda \quad (5)$$

Here h_t and h_r are the height of sender and receiver antennas respectively above the ground, L is the system loss and λ is the signal wavelength. Crossover distance is 87m [12].

Also we calculated the amount of energy consumed by a sensor node in sensing the environment and is equal to

$$E_{Sense} = \alpha \cdot I / UnitTime \quad (6)$$

Where α is the amount of energy consumed by a sensor node to sense a single bit and I is the total number of bits in a message being sensed.

B. Network Architecture

The network architecture of our proposed model is based on the following assumptions:

- Base Station is located far away from sensor field and is immobile.
- Sensor nodes are energy-constrained and have the same initial energy.
- Communication channels are symmetric in nature i.e.: energy consumed in transmission on a particular channel is equal to energy consumed for reception on it.
- Sensor nodes have the capabilities to adjust their transmission power.
- Sensor nodes sense the environment at a fixed rate and always have data to send.

Additionally, our network consists of a small percentage of High Energy nodes (other than sensor nodes) which have higher energy than the sensor nodes deployed [25-33]. Also, optimal number of CHs in each round is assumed around five percent of the sensor nodes. The reason we have chosen five percent of high energy nodes to balance between computational complexity to run our algorithm and lower data aggregation ratio against high energy efficiency and transmission distance.

Our proposed algorithm is based on centralized approach: Cluster formation and CHs selection is performed by the Base Station. We believe our approach is unique because it uses a hybrid methodology: For Cluster formation and CHs selection, it is homogenous because only sensing nodes can be elected as CHs and belongs to any of the Clusters formed by the BS. All these sensing nodes have the same initial energy at the time of deployment. For transmission of energy status of

nodes and location information, it is heterogeneous because such information is only transmitted by High-Energy nodes which have higher energy than sensing nodes. High-Energy nodes do not perform any sensing and only perform transmission of location information and residual energy to BS at the start of each round.

In this section the flowchart for our proposed algorithm is presented. The flowchart illustrates the Setup phase of our algorithm followed by the network operation. Evaluation of residual energy levels by the Base Station is also presented here which explain the queuing mechanism being deployed by the Base Station and the selection criteria for a node to be elected as Cluster Head. The BS maintains a single queue which contains the location information and residual energy information of each node. Base Station chooses CHs from the queue by evaluating each node's residual energy against average energy threshold value. Location information of each sensing node (other than High-Energy nodes) is also maintained in the queue. Once BS elects the CHs nodes, location information of each node is used to transmit this information to each individual node. High-Energy nodes do not participate in CH election or Cluster formation [34-38]. The flowchart, network operation and evaluation procedure by the Base Station in our proposed approach are presented in this section.

C. Energy Model

Based on [12], we have calculated the energy consumed by CH nodes, Leader node (LN), High-Energy nodes (HENs) and normal sensing nodes (SN) of Figure 7. As previously said, our network has 100 nodes (N=100) (other than High-Energy nodes) in a 100m x 100m sensor field. The base station is located 90 m from its nearest sensor neighbor. The energy consumed by the CH nodes is

$$E_{CH} = m E_{elec} (N/k) + m E_{DA} ((N/k) - 1) + m \epsilon_{FS-amp} d^2_{to-LN} \quad (8)$$

Unlike LEACH-C and its variants, the CHs in our network transmit the data to another CH having large energy (Leader node) instead of BS. Since Leader node is located in the field of above dimensions so free space model is used. k is the optimal number of Clusters (here k=5), E_{DA} is the

energy consumed in data aggregation while m is the message being transmitted by each Clustering node. Next, each CH transmits the aggregated data to the Leader node (LN).

The energy consumption of the High-Energy node (HEN) is calculated as:

$$E_{HEN} = m E_{elec} + m \epsilon_{Two-Ray-amp} d^4_{to-BS} \quad (9)$$

Here, m is the message sent by each node containing its location information and residual energy during Status sub-phase. R is the number of nodes. Here R is variable as the numbers of nodes, which transmit their location and energy information to HEN nodes varies. As HEN nodes transmit this information directly to Base Station which is far away from sensor field, so Two-Ray ground propagation model is used ($d > d_{crossover}$). If the HEN nodes are near the Base Station, then Free Space model is used. In our algorithm, Two-Ray ground propagation model will always be used due to our network specification (Distance of Base Station from Sensor field).

The energy consumed by the Leader node is

$$E_{LN} = m E_{elec} (N/k) + m E_{DA} ((N/k) - 1) + n E_{DA} (\sum_{i=1}^{k-1} CH) + m \epsilon_{Two-Ray-amp} d^4_{to-BS}; \quad d > d_{crossover} \quad (10)$$

As the sensor nodes are at a distance greater than crossover from Base Station, so Two-Ray ground propagation model is used to model the energy consumption of the Leader node.

In equation 10, the Leader node collects data from its Clustering members as well (since Leader node is one of the CH nodes having high energy) and also it gathers data from other CH nodes. In equation 10, n is the number of messages transmitted by the CH nodes and k-1 is the number of optimal Clusters from which the data is send. If k is 5, this means four CHs will transmit data to the Leader node.

The energy consumed by any sensing node during Status sub-phase is given by:

$$E_{\text{Sensing-Node}} = mE_{\text{elec}} + m \epsilon_{\text{FS-amp}} d_{\text{to-HEN}}^2 \quad (11)$$

Sensing node can be any node in the network other than HEN nodes because during Status sub-phase there is neither CH nor Leader node. Once Clusters are formed and the Clustering nodes start transmitting their data to the CH, their energy consumption is calculated as:

$$E_{\text{Non-CH}} = mE_{\text{elec}} + m \epsilon_{\text{FS-amp}} d_{\text{to-CH}}^2 \quad (12)$$

Finally, the total energy consumed in the network is equal to the sum of energy consumed by all the nodes of the network and is given in Equation 13.

$$E_{\text{Total}} = E_{\text{Sensing-Node}} + E_{\text{CH}} + E_{\text{Non-CH}} + E_{\text{LN}} + E_{\text{HEN}} \quad (13)$$

IV. CONCLUSION

All Centralized Cluster-based routing protocols efficiently utilize limited energy of the nodes by rotating nodes as CHs. However, these protocols require nodes to transmit location and energy information to Base Station at the start of each round. In order to reduce the burden on sensor nodes, we proposed an algorithm in which a small percentage of High-energy nodes are used to convey each node's information to the Base Station. These nodes remain in sleep mode most of the time. In order to reduce energy load further, Cluster Head advertisement phase is eliminated as this function is performed by Base Station which has sufficient energy resources. These CHs gather data from their respective Clusters and transmit to a Leader node being selected by the Base Station based on its residual energy. This node transmits the final aggregated data to the Base Station.

We developed an energy model for our proposed approach and this energy model can be applied to any clustering protocol depending on the application and the choice of nodes to be used. We believe, the proposed energy model is the first of its kind in Cluster-based routing protocols. However, we have also calculated energy levels for Leader node, Sensing Node and High-Energy node to compute overall energy consumptions in a WSN.

REFERENCES

- [1]. Akyildiz, I.F., Su W., Sankarasubramaniam Y., Cayirci, E: Wireless sensor networks: a survey. Elsevier Computer Networks 38, pp. 393-422 (2002)
- [2]. Khan. F., Bashir, F. (2012). *Dual Head Clustering Scheme in Wireless Sensor Networks*. in the IEEE International Conference on Emerging Technologies (pp. 1-8). Islamabad: IEEE Islamabad.
- [3]. Syed Roohullah Jan, Khan. F., Zaman. A., (2015) *The Perception of students about Mobile Learning at University Level*. in the khgresearch.org NO. CONTENTS PAGE NO Turkey, pp.97
- [4]. Khan. F., Nakagawa. K. (2012). *Cooperative Spectrum Sensing Techniques in Cognitive Radio Networks*. in the Institute of Electronics, Information and Communication Engineers (IEICE), Japan , Vol -1, 2.
- [5]. Puthal, D., Nepal, S., Ranjan, R., & Chen, J. (2015). A Dynamic Key Length Based Approach for Real-Time Security Verification of Big Sensing Data Stream. In *Web Information Systems Engineering-WISE 2015* (pp. 93-108). Springer International Publishing.
- [6]. M. A. Jan, P. Nanda, X. He, Z. Tan and R. P. Liu, "A robust authentication scheme for observing resources in the internet of things environment" in 13th International Conference on Trust, Security and Privacy in Computing and Communications (TrustCom), pp.205-211, 2014, IEEE.
- [7]. Heintzelman, W. R., Chandrakasan, A., Balakrishnan, H.: An Application-Specific Protocol Architecture for Wireless Microsensor Networks. *Proceedings of IEEE Transaction on Wireless Communication* VOL. 1, NO. 4, pp.660-670 (2002)
- [8]. Khan. F., Nakagawa, K. (2012). *Performance Improvement in Cognitive Radio Sensor Networks*. in the Institute of Electronics, Information and Communication Engineers (IEICE) , 8.
- [9]. Puthal, D., Nepal, S., Ranjan, R., & Chen, J. (2015, August). DPBSV--An Efficient and

- Secure Scheme for Big Sensing Data Stream. InTrustcom/BigDataSE/ISPA, 2015 IEEE (Vol. 1, pp. 246-253). IEEE.
- [10]. M. A. Jan, P. Nanda and X. He, “Energy Evaluation Model for an Improved Centralized Clustering Hierarchical Algorithm in WSN,” in *Wired/Wireless Internet Communication*, Lecture Notes in Computer Science, pp. 154–167, Springer, Berlin, Germany, 2013.
- [11]. Heinzelman, W. R., Chandrakasan, A., Balakrishnan, H.: Energy-Efficient Communication Protocol for Wireless Microsensor Networks. Proceedings of 33rd Hawaii International Conference on System Sciences (2000)
- [12]. Khan. F., Kamal, S. A. (2013). *Fairness Improvement in long-chain Multi-hop Wireless Adhoc Networks*. International Conference on Connected Vehicles & Expo (pp. 1-8). Las Vegas: IEEE Las Vegas, USA.
- [13]. Puthal, D., Nepal, S., Ranjan, R., & Chen, J. (2016). A dynamic prime number based efficient security mechanism for big sensing data streams. *Journal of Computer and System Sciences*.
- [14]. M. A. Jan, P. Nanda, X. He and R. P. Liu, “Enhancing lifetime and quality of data in cluster-based hierarchical routing protocol for wireless sensor network”, 2013 IEEE International Conference on High Performance Computing and Communications & 2013 IEEE International Conference on Embedded and Ubiquitous Computing (HPCC & EUC), pp. 1400-1407, 2013.
- [15]. Jabeen. Q., Khan. F., Khan, Shahzad, Jan. M. A., Khan. S.A (2016). *Performance Improvement in Multihop Wireless Mobile Adhoc Networks*. in the Journal Applied, Environmental, and Biological Sciences (JAEBS), Print ISSN: 2090-4274 Online ISSN: 2090-4215
- [16]. Muruganathan, S. D., Daniel C. F., Rolly, M.A., Bhasin, I., Fapojuwo, A O.: A Centralized Energy-Efficient Routing protocol for Wireless Sensor Networks, Proceedings of IEEE Radio Communications (2005)
- [17]. Khan. F., Nakagawa, K. (2013). *Comparative Study of Spectrum Sensing Techniques in Cognitive Radio Networks*. in IEEE World Congress on Communication and Information Technologies (p. 8). Tunisia: IEEE Tunisia.
- [18]. Puthal, D., Sahoo, B., & Sahoo, B. P. S. (2012). Effective Machine to Machine Communications in Smart Grid Networks. *ARPN J. Syst. Softw.*© 2009-2011 *AJSS Journal*, 2(1), 18-22.
- [19]. Khan. F., (2014). *Secure Communication and Routing Architecture in Wireless Sensor Networks*. the 3rd Global Conference on Consumer Electronics (GCCE) (p. 4). Tokyo, Japan: IEEE Tokyo.
- [20]. M. A. Jan, P. Nanda, X. He and R. P. Liu, “PASCCC: Priority-based application-specific congestion control clustering protocol” *Computer Networks*, Vol. 74, PP-92-102, 2014.
- [21]. S. Ghiasi et al., “Optimal Energy Aware Clustering in Sensor Networks,” *MDPI Sensors*, vol. 2, no. 7, pp. 258–269 (2002)
- [22]. Khan. F., (2014). *Fairness and throughput improvement in mobile ad hoc networks*. in the 27th Annual Canadian Conference on Electrical and Computer Engineering (p. 6). Toronto, Canada: IEEE Toronto.
- [23]. Mian Ahmad Jan and Muhammad Khan, “A Survey of Cluster-based Hierarchical Routing Protocols”, in *IRACST–International Journal of Computer Networks and Wireless Communications (IJCNWC)*, Vol.3, April. 2013, pp.138-143.
- [24]. Khan. S., Khan. F., (2015). *Delay and Throughput Improvement in Wireless Sensor and Actor Networks*. 5th National Symposium on Information Technology: Towards New Smart World (NSITNSW) (pp. 1-8). Riyadh: IEEE Riyad Chapter.
- [25]. Khan. S., Khan. F., Jabeen. Q., Arif F., Jan. M. A., Khan. S.A (2016). *Performance Improvement in Wireless Sensor and Actor Networks*. in the Journal Applied, Environmental, and Biological Sciences Print ISSN: 2090-4274 Online ISSN: 2090-4215
- [26]. Puthal, D., & Sahoo, B. (2012). *Secure Data Collection & Critical Data Transmission in Mobile Sink WSN: Secure and Energy*

efficient data collection technique.

- [27]. Varma, S., Nigam, N., Tiwary, U.S.: *Base Station Initiated Dynamic Routing Protocol for Heterogeneous Wireless Sensor Network using Clustering* Proceedings of IEEE Wireless Communication and Sensor Networks (2008)
- [28]. Mian Ahmad Jan and Muhammad Khan, "Denial of Service Attacks and Their Countermeasures in WSN", in IRACST–International Journal of Computer Networks and Wireless Communications (IJCNCW), Vol.3, April. 2013.
- [29]. Qamar Jabeen, Khan. F., Muhammad Nouman Hayat, Haroon Khan, Syed Roohullah Jan, Farman Ullah, " A Survey : Embedded Systems Supporting By Different Operating Systems", International Journal of Scientific Research in Science, Engineering and Technology(IJSRSET), Print ISSN : 2395-1990, Online ISSN : 2394-4099, Volume 2 Issue 2, pp.664-673, March-April 2016.
- [30]. M. A. Jan, P. Nanda, X. He and R. P. Liu, "A Sybil Attack Detection Scheme for a Centralized Clustering-based Hierarchical Network" in Trustcom/BigDataSE/ISPA, Vol.1, PP-318-325, 2015, IEEE.
- [31]. KUSDARYONO, A., LEE, K. O.: *A Clustering Protocol with Mode Selection for Wireless Sensor Network* Proc. Journal of Information Processing Systems, Vol.7, No.1 (March 2011)
- [32]. Syed Roohullah Jan, Syed Tauhid Ullah Shah, Zia Ullah Johar, Yasin Shah, Khan. F., "An Innovative Approach to Investigate Various Software Testing Techniques and Strategies", International Journal of Scientific Research in Science, Engineering and Technology(IJSRSET), Print ISSN : 2395-1990, Online ISSN : 2394-4099, Volume 2 Issue 2, pp.682-689, March-April 2016. URL : <http://ijsrset.com/IJSRSET1622210.php>
- [33]. Khan. F., Khan. F., Jabeen. Q., Jan. S. R., Khan. S., (2016) *Applications, Limitations, and Improvements in Visible Light Communication Systems* in the VAWKUM Transaction on Computer Science Vol. 9, Iss.2, DOI: <http://dx.doi.org/10.21015/vtcs.v9i2.398>
- [34]. Heinzelman, W.R.: *Application-Specific Protocol Architectures for Wireless Networks*. Ph.D. Dissertation (2000)
- [35]. Syed Roohullah Jan, Khan. F., Muhammad Tahir, Shahzad Khan., (2016) "Survey: Dealing Non-Functional Requirements At Architecture Level", VFAST Transactions on Software Engineering, (Accepted 2016)
- [36]. M. A. Jan, "Energy-efficient routing and secure communication in wireless sensor networks," Ph.D. dissertation, 2016.
- [37]. Syed Roohullah Jan, Faheem Dad, Nouman Amin, Abdul Hameed, Syed Saad Ali Shah, " Issues In Global Software Development (Communication, Coordination and Trust) - A Critical Review", International Journal of Scientific Research in Science, Engineering and Technology(IJSRSET), Print ISSN : 2395-1990, Online ISSN : 2394-4099, Volume 2 Issue 2, pp.660-663, March-April 2016. URL : <http://ijsrset.com/IJSRSET1622207.php>
- [38]. Azim. N., Majid. A., Khan. F., Tahir. M., Safdar. M., Jabeen. Q., (2016) *Routing of Mobile Hosts in Adhoc Networks*. in the International Journal of Emerging Technology in Computer Science and Electronics (in press)
- [39]. Azim. N., Qureshi. Y., Khan. F., Tahir. M., Syed Roohullah Jan, Majid. A., (2016) *Offsite One Way Data Replication towards Improving Data Refresh Performance*. in the International Journal of Computer Science and Telecommunications (in press)
- [40]. Azim. N., Majid. A., Khan. F., Tahir. M., Syed Roohullah Jan, (2016) *People Factors in Agile Software Development and Project Management*. in the International Journal of Emerging Technology in Computer Science and Electronics (in press)
- [41]. Azim. N., Khan. A., Khan. F., Syed Roohullah Jan, Tahir. M., Majid. A. (2016) *Offsite 2-way Data Replication towards Improving Data Refresh Performance*. in the International Journal of Engineering Technology and Applications (in press)
- [42]. Azim. N., Ahmad. I., Khan. F., Tahir. M.,

- Majid. A., Syed Roohullah Jan, (2016) *A New Robust Video Watermarking Technique Using H.264/AAC Codec Luma Components Based On DCT*. in the International Journal of Advance Research and Innovative Ideas in Education (in press)
- [43]. Syed Roohullah Jan, Ullah. F., Khan. F., Azim. N, Tahir. M. (2016) *Using CoAP protocol for Resource Observation in IoT*. in the International Journal of Engineering Technology and Applications (in press)
- [44]. Syed Roohullah Jan, Ullah. F., Khan. F., Azim. N, Tahir. M, Safdar, Shahzad. (2016) *Applications and Challenges Faced by Internet of Things- A Survey*. in the International Journal of Emerging Technology in Computer Science and Electronics (in press)
- [45]. Tahir. M., Syed Roohullah Jan, Azim. N., Khan. F., Khan. I. A., (2016) *Recommender System on Structured Data*. in the International Journal of Advance Research and Innovative Ideas in Education (in press)
- [46]. Tahir. M., Khan. F., Syed Roohullah Jan, Khan. I. A., Azim, N., (2016) *Inter-Relationship between Energy Efficient Routing and Secure Communication in WSN*. in the International Journal of Emerging Technology in Computer Science and Electronics (in press)
- [47]. Safdar. M., Khan. I. A., Khan. F., Syed Roohullah Jan, Ullah. F., (2016) *Comparative study of routing protocols in Mobile adhoc networks*. in the International Journal of Computer Science and Telecommunications (in press)
- [48]. M. A. Jan, P. Nanda, M. Usman and X. He. 2016. *PAWN: A Payload-based mutual Authentication scheme for Wireless Sensor Networks*, in 15th IEEE International Conference on Trust, Security and Privacy in Computing and Communications (IEEE TrustCom-16), "accepted".
- [49]. M. Usman, M. A. Jan and X. He. 2016. *Cryptography-based Secure Data Storage and Sharing Using HEVC and Public Clouds*, Elsevier Information sciences, "accepted".
- [50]. M. A. Jan, P. Nanda, X. He and R. P. Liu. 2016. *A Lightweight Mutual Authentication Scheme for IoT Objects*, IEEE Transactions on Dependable and Secure Computing (TDSC), "Submitted".
- [51]. M. A. Jan, P. Nanda, X. He and R. P. Liu. 2016. *A Sybil Attack Detection Scheme for a Forest Wildfire Monitoring Application*, Elsevier Future Generation Computer Systems (FGCS), "Submitted".