Energy Efficient Data Collection Methods in Wireless Sensor Networks: A Survey

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Abstract - **Wireless sensor networks (WSN) consist of many sensor nodes deployed in a large area for sensing the events occurring in that environment. The main source of energy consumption in sensor networks is the data collection process. Data collection should be done with minimum energy expenditure, latency and packet collision. Overcoming these issues is a challenging task in WSN. This paper presents a survey of various techniques used for data collection with minimum energy consumption.**

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***Index Terms* – Wireless sensor network, Clustering, Data collection, Mobile sink**

I. INTRODUCTION

Wireless sensor network has wide range of application in military [1, 2], home/industries, health [3], environmental monitoring [4, 5] etc. Sensor nodes which are deployed in large areas will continuously monitor the events, collect the sensed data and forward it to a central base station for further processing. Here the main problem is the limited power supply of sensor nodes. Sensor nodes are equipped with a battery, which are not replaceable in some cases. The main source of energy consumption in sensor network is the data transfer process. When the number of data transmissions reduce, energy saving will be more. During the data transfer process, nodes which are near the sink will face high traffic load compared to other nodes. This leads to quick energy dissipation in these nodes, resulting in the formation of energy holes. An analytical model for the energy hole problem is developed in [6]. So minimizing the energy consumption while maintaining the delay requirements, packet delivery ratio etc. is a challenging task in WSN. Many methods are proposed to solve these problems.

II. WIRELESS SENSOR NETWORK: OVERVIEW

Wireless sensor networks consist of large number of sensor nodes distributed in an area for monitoring physical or environmental phenomenon. Basic components of wireless sensor networks are shown in Figure 1. The power source is a battery having limited power supply. Transmission and reception of data by the radio transceivers results in large amount of energy expenditure in the network.

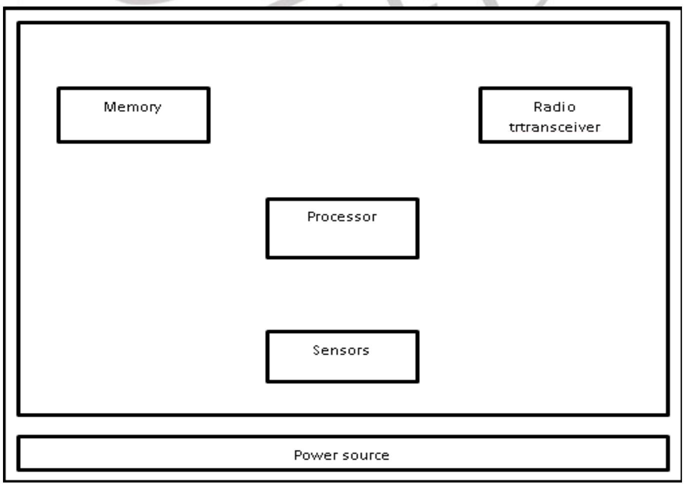

Figure 1 Wireless Sensor Network Components

If the data transmission is done in energy efficient way then the network lifetime can be improved. For efficient data transmission, wireless networks adopt much architecture such as layered architecture, cluster based and mobile sink based architectures to solve these problems.

III. ENERGY EFFICIENT DATA COLLECTION TECHNIQUES

Data collection should be done in an energy efficient way for improving the lifetime of the sensor network. Various methods for energy efficient data collection are proposed, which includes clustering, data reduction, collision free algorithms, mobile relay and mobile sink based methods.

Clustering Based Methods

Clustering techniques are widely adopted in wireless sensor networks since it helps to achieve high energy efficiency by selecting the best suitable cluster heads for data aggregation. In [7], a clustering based data collection protocol is proposed, which is called as LEACH (Low Energy Adaptive Clustering Hierarchy). This protocol is designed in such a way so as to minimize the total energy consumption by distributing the traffic load among different nodes at different times. This is achieved by selecting cluster heads and randomly rotating these cluster heads to evenly distribute the traffic load among all sensors. LEACH selects cluster heads in a random manner and does not require any control information from the base station or knowledge of the network for its operation. ALEACH (Advanced low energy adaptive clustering hierarchy) [8] is an advanced version of LEACH in which nodes make autonomous decisions without any central intervention. An algorithm for rotating cluster heads for balancing the traffic load is also proposed here. In [9], a single level clustering algorithm is described where the sensors join to each cluster heads on receiving the advertisement from the cluster heads. A hierarchical clustering algorithm is also proposed here where more than one level of clustering is done. Here the sensors first sense the data and send it to their corresponding level 1 cluster heads. Level 1 cluster heads will aggregate this data and forward it to level 2 cluster heads and so on. This distributed algorithm helps to reduce the node's energy consumption and to improve the network lifetime more than that of LEACH. In [10], HEED (hybrid energy efficient distributed clustering) protocol is proposed. This is a cluster based protocol in which cluster head selection is done based on the residual energy of the sensor nodes and the nodes join to the cluster heads in such a way so as to minimize the total communication cost. Cluster head selection is done with more number of iteration and it terminates with uniform cluster head distribution across the network. HEED also considers node density, intracluster and intercluster transmission ranges. Appropriate bounds for each of these parameters are also calculated and with these bounds HEED provides better connectivity for the network. In [11], an energy efficient clustering scheme (EECS) is proposed. EECS is similar to LEACH protocol. EECS operates in four phases which are node deployment phase, cluster formation, cluster head election and data transfer phase. Each phase is completed with the help of control messages. EECS selects cluster heads based on residual energy and it achieves better cluster distribution without iterations. Traffic load is balanced among cluster heads based on distance based load distribution techniques. In the cluster head election process the most suitable cluster head is selected with little control overhead and a weighted function is used to construct traffic balanced clusters. In [12], an energy efficient data collection scheme for wireless sensor network based on graph theory is proposed. Here the sensor network is modeled as a graph G (V, E) where V is the set of sensor nodes and E is the set of edges connecting these sensor nodes. Here the cluster heads are selected from the center of the graphs. A hierarchical clustering scheme is used here for data collection. This scheme mainly focuses on the reduction of hop count for data transmission and thereby improves the energy savings. In [13], Time controlled clustering algorithm (TCCA) is proposed which uses the rotating cluster head election for reducing the network wide energy consumption. Operation of TCCA is done in two phases, cluster setup phase and steady state phase. Data collection, aggregation and data transfer occurs in steady state phase. Residual energy of nodes is also taken into account for cluster head election. TCCA differs from other protocols because here the cluster formation is controlled by TTL (Time to Live) messages. Message time stamp is used to measure the distance between the nodes and cluster heads so as to control the cluster size for collision free data transmission.

In [14] a new clustering mechanism, Unequal Cluster based Routing (UCR) is proposed. Previous methods of clustering mainly consist of two phases which are cluster head selection and rotation of cluster heads for distributing the energy among sensor nodes. These methods don't consider the hot spot problem where in the cluster heads near the base station get disconnected from the network due to the heavy traffic load. In UCR, the clusters near the base station is selected with small sizes so that the energy consumption for inter cluster communication can be reduced and the hot spot problem can be minimized. In [15], a cluster formation protocol is proposed to achieve energy efficiency in WSN during data collection without compromising the application specific quality. Here, randomized, adaptive and self-configuring clusters are formed with the selection of cluster heads for the aggregation of data coming from other nodes. The main advantage of this method is that it uses the compression of data in cluster heads for reducing the amount of data to be transferred to the base station. The energy required to transmit the consolidated data is found to be less than that of the energy required to send the whole data. Simulation results show that this protocol achieves an order of magnitude increase in system lifetime. In [16], a cluster based routing protocol that supports mobility of sensor nodes is proposed. This protocol efficiently assigns unused time slots for each node and so it is called as traffic adaptive and mobility adaptive. Simulation results show that this protocol improves energy usage and decreases the packet delivery ratio. In [17], a combined cluster based and tree based protocol is used to improve the reduction of power dissipation in a wireless sensor network. This protocol operates in three phases which are clustering phase, constructing cluster based tree and data gathering phase. Cluster head is selected from the center of each cluster and the minimum spanning trees are constructed for data transmission in an energy efficient way. Every node transmits the gathered data to upper level nodes until it reaches the sink. This method reduced the power consumption on avoiding direct communication between the sink and the sensor nodes moreover the tree based structure reduced the communication overhead.

In [18], a clustering mechanism is proposed based on slepian wolf coding .To reduce the amount of data generated and the number of data transmissions, a slepian wolf code based energy efficient clustering algorithm (SWEEC) is used here. Both the correlation structure of generated data and the distance of each node from the sink are taken into account for the cluster head selection process. So here a node which is closer to the sink will get higher priority while cluster head selection. Simulation results show that the proposed SWEEC algorithm reduces the energy consumption compared with the other slepian wolf code based clustering algorithms [19,20]. In [21], an energy efficient cluster based protocol (EECP) is proposed. It has 3 rounds of operations which are clustering phase, chain formation, and data gathering. Weight of each node, based on residual energy is calculated to select the cluster heads and later the cluster head will create a chain connecting different nodes and also different cluster heads for data transmission. The use of chain based routing offers the advantage of small distance transmission for each node and thereby improves the energy consumption.

Collision Free Protocols for Data Collection

Most of the MAC (Medium Access Control) protocols use low duty cycling for energy conservation in wireless sensor networks. MAC protocol with duty cycling can be classified into three categories which are TDMA schemes, contention based protocols and hybrid protocols. Similar to the channel access used in TDMA schemes for channel access here also nodes turn on their radios only during their allotted time slots so that unnecessary energy consumption can be avoided. Contention based protocols integrate the channel access functions with the sleep wake up schemes for power management. Hybrid protocols switch between TDMA and contention based protocols based on the level of contention.

In TDMA based protocols, time is divided into many slots and each time slot is assigned for node's transmission and reception. In [22, 23, 24] clustering is done and cluster head assigns the timeslots for each node. A low complexity time slot allocation mechanism is proposed in [25] which is named as light weight medium access protocol (LMAC). Here the nodes select the time slots randomly. Control messages and data units are send directly so that the energy needed for preamble transmission can be saved. Drawback of LMAC is the fixed frame length. So in [26], adaptive information centric LMAC (AI-LMAC) is proposed in which slots can be selected based on traffic needs. In [27] traffic adaptive MAC (TRAMA) is introduced. This protocol helps to reduce collision during packet transmission and also allows nodes to switch to low power state whenever they are not transmitting or receiving. TRAMA finds the traffic load of each node and avoids the assignment of timeslots to nodes which have no data to send. FLAMA (Flow Aware Medium Access) [28] is related to TRAMA and it is mainly used for periodic monitoring applications. This protocol mainly focuses on reducing the unnecessary traffic information exchange. Here a pull based mechanism is used so that the data is transferred only when it is requested. In [29], a traffic adaptive periodic data collection MAC (TA-PDC-MAC) is proposed to reduce the energy consumption of sensor nodes used in environmental monitoring applications. Unlike the existing PDC-MAC protocol TA-PDC-MAC supports network with different data generation rate. Here the sink node will compute the time schedule for each node and this staggered time schedule will help to reduce the delay in the network and also saves energy needed for idle listening. In [30], TDMA scheduling with adaptive slot stealing and parallelism (TDMA-ASAP) is proposed which uses parallel transmissions, slot stealing and adaptive sleeping between transmissions for energy saving. TDMA-ASAP allows the network to adapt changing conditions but it is only applicable during periods of light load. In [31], a TDMA based coloring algorithm is proposed which make use of the spatial reuse of the channel for data transmission. An advanced version of this method which uses parallelism and allocates time slot in an energy efficient way is proposed in [32]. Here a MAC protocol named as I queue MAC is introduced which make use of the queue length of each node to understand the need of time slots and allocate it based on the queue length.

The most popular contention based MAC protocol is BMAC [33]. BMAC uses sleep/wakeup scheme based on low power listening. Here the nodes periodically wake up for checking the channel for any activity. If any channel activity is detected then it will remain active and transmit the data. In SMAC [34], nodes use sync packets for the coordination of sleep/wakeup periods. TMAC [35] is an enhanced version of SMAC which is mainly designed for variable traffic load. Even though these protocols are energy efficient it increases latency for data forwarding since a node has to wait till the wakeup time for transmission. In [36, 37] DMAC, an adaptive duty cycle protocol is proposed in which the node's active periods along the multihop paths are made adjacent to minimize the latency. In the existing SMAC protocol, power saving is achieved by controlling active/sleep periods. This process requires the exchange of more control packets which causes unnecessary energy expenditure. So in [38] preamble sampling is used instead of RTS/CTS packets for achieving energy saving. In [39], medium reservation preamble based MAC [MRPM] is proposed which has two main advantages. First one is that it assigns a single time frame for data and sync traffic which is a short listen period. Second one is that non transmitters can go to sleep mode during the channel contention so energy can be saved. Contention window adaptive MAC protocols are proposed in [40, 41]. In [40], based on the queue length of each node the contention window is selected and in [41], contention window is selected by evaluating the network traffic load and competition among neighbors. In [42, 43], adaptive duty cycle SMAC is proposed. This protocol assigns higher priority to the nodes having more packets to send in order to access the channel.

Hybrid MAC switches between TDMA and CSMA based on level of contention. Most interesting hybrid protocol is ZMAC [44]. ZMAC switches between CSMA and TDMA based on the level of contention. Like CSMA, ZMAC achieves high channel utilization and low latency at low contention and like TDMA high channel utilization at high contention. Synchronization errors and slot assignment failures are low for ZMAC. In [45], a new hybrid MAC protocol that combines the energy efficiency features of both TDMA based and contention based protocol is developed. This protocol allows more than one neighbor of a node to send data packet to it in the same frame. Like SMAC this protocol uses short frame structure to improve the energy efficiency. In [46], data aggregation MAC is proposed to avoid collision under high traffic load. Here the slot assignment is done based on TDMA and then node goes to sleep mode for saving energy. When an emergency situation arises nodes change their behavior and allow contention in TDMA slots. The data aggregation MAC outperforms others in all aspects.

Data Reduction Techniques

The Data reduction is the process of reducing the original data sensed by the sensor nodes to a small amount of data such that the original data can be retrieved without any loss. Reduced data requires less amount of energy for transmission than that of the original data. Data prediction techniques can be used to reduce the amount of data transmitted with the use of a prediction model for sensing phenomenon. The queries can be answered by this model instead of sending the actual data and it can be done only if the model exactly represents the sensing phenomenon at a given instant. The model is valid only if the predicted value is comparable with the actual data. Similar approaches are proposed in [47, 48]. The base model used here is probabilistic and exploits the spatial and temporal correlation among the sensed data. In [49], an extension of [47] is proposed where a probabilistic model is used to implement the data prediction.

To reduce the amount of data to be acquired from the transducers adaptive sampling can be done. Here the temporal correlation among the data is exploited to reduce the data acquisition. Temporal correlation among the sensed data is used in [50] for snow monitoring in avalanche forecast. Here the sampling frequency needed to reconstruct the original data is not known priori so sometimes it will result in oversampling of the data. To overcome this problem in [51] an adaptive algorithm that periodically estimates the sampling frequency is proposed. The sink will inform the estimated sampling rate to all other nodes. In [52] sampling rate are derived from a Kalman filter. Here the adaptive sampling mechanism is coupled with bandwidth reservation mechanism to ensure that the traffic does not exceed the network capacity. To reduce the number nodes that have to report the data to the sink, spatial correlation is used in [53]. Correlation-based Collaborative MAC protocol (CC-MAC) is proposed here to reduce the number of reporting nodes. Iterative Node Selection (INS) algorithm is used to find the correlation radius and it will be broadcasted to all nodes. Based on these correlation radius one node will be selected as the representative node for data transmission. Event MAC (EMAC) prevents the transmission of redundant information during the channel access phase. A flood warning system based on adaptive sampling is proposed in [54].

Data compression is another way of data reduction for saving the energy needed for data transmission. Various algorithms are proposed to compress the data so that only few bits are needed to be transmitted instead of actual data. In [55], coding by ordering data compression scheme is proposed. Instead of sending individual data streams from the sensor nodes, only an aggregated data stream is transmitted with the help of aggregator nodes. This reduces energy and packet collision since fewer nodes are transmitting the information to the destination. In [56], PINCO (Pipelined In-Network Compression) is proposed where the buffered sensor data is compressed using pipelined compression scheme. In [57, 58], distributed compression schemes are used and the advantage of this scheme is that only the side information is required to code the actual source information. In [59], an adaptive loss less compression algorithm is presented. This scheme dynamically adjusts to the change in the number of sources. Additionally, this algorithm can be used in monitoring systems that have different types of data. ALDC is suitable for both real-time application as well as delay sensitive applications. In [60, 61], compression is done based on correlation among the data generated by nearby sensor nodes. These methods also consider the temporal effect of correlation among the data stream also improving the performance.

In [62], the spatial correlation of data is exploited in WSN having multiple sinks. Based on the special correlated sensor readings, an algorithm is proposed to select a subset of sensor nodes called sources to upload the data to the sinks. Selection of sources is considered as a binary integer linear programming problem and two heuristic algorithms are developed to find the approximate solution, which are the correlation first algorithm and distance first algorithm. Results show that this method reduces the number of sources and improved the energy saving. In [63], spatial correlation among the sensor readings from adjacent nodes is taken into account for improving the lifetime of the sensor network. An energy aware iterative sampling framework is proposed here. To determine the data redundancy, inverse distance weighting interpolation method (IDW) is used. Based on the result of this algorithm after a limited number of iteration, fewer nodes will be selected for data transfer and other nodes will go to sleep mode while these nodes are transmitting. In [64], an algorithm using dual prediction and clustering is proposed. This algorithm operates in two phases where in the first phase; the nodes will be partitioned into clusters based on the correlation metric. In the second phase, nodes will send the data to the sink according to the schedule generated by the sink. A prediction algorithm predicts the future values and if it is less than a particular threshold the data will not be send to the sink.

Mobility Based Approaches

Many protocols which are developed to improve the energy efficiency in wireless sensor networks are discussed above. None of them introduced the concept of mobility for energy efficient data collection. Mobile elements can be used in the network for collecting data from other nodes so that the energy consumption for data forwarding can be reduced. Mobile elements can be mobile relays or mobile sinks. Mobile relays will collect data, store it and then forward it to the sink. Mobile sinks are the destination or endpoints which can be used to collect data autonomously. In [65,66,67], the method proposed is the use of mobile entities called MULEs (Mobile Ubiquitous LAN Extensions) to collect data sensed by the sensor nodes which are scattered in a large farm. Three tier architecture for data collection is proposed here and an animal is used as the mobile relay. This MULE will collect data from nodes, store it and transfer it to the wired access points. As the sensor node has to transmit only in a short range, this method of data collection improves the energy saving. Key advantages of the MULE architecture are its robustness, scalability and reliability. A drawback of these systems is the increased latency in data collection. The most famous approach in mobile relay based communication method is the message ferrying (MF) technique. Ferries are special nodes in the network which are selected for message relaying. In [68, 69], Message ferries are used and it will move around the network for delivering messages to individual nodes. This process will lead to high data delivery latency, however the nodes can save energy with the knowledge of ferry's location. A power management framework is also proposed here in which the nodes can select suitable power management modes based on ferries location. If the ferry is out of range a node can go for sleep mode. In searching mode a node will listen to beacons and in communicating mode, a node will wake up to communicate with the ferry. In [70], also ferry act as a relay for data transfer. Two variations of message ferrying is proposed here. First one is node initiated message ferrying scheme (NIMF) and the other one is ferry initiated message ferrying scheme (FIMF). In NIMF scheme ferry moves through a fixed path which is known by all other nodes. So the nodes will take movement to meet up with ferry for message transfer. In FIMF, ferry will initiate the proactive movement for message transfer.

Mobile sink based data collection methods are proposed in [71, 72]. Here one or more mobile sinks move through the network area for collecting the data generated by other nodes. Data collection in urban scenario is proposed in [73]. Here people act as mobile sink for collecting environmental data. These methods did not consider the high latency of data collection. To reduce the latency in data collection, TSP (Travelling Salesman Problem) based data collection methods were proposed. Here the main aim is to find a minimum distance path for the sink's data collection. In [74], Traveling Sales man Problem with Neighborhood (TSPN) algorithm is proposed to find a shortest travelling path for the mobile sink's data collection. Here the sink node has to visit only the neighborhood of sensor nodes for collecting data. An algorithm which requires the knowledge of sensor location was used to find the optimal set of points for the mobile sink path. In [75], another TSP-based algorithm called label-covering algorithm is proposed which considers WSN as a graph, where there are vertices at each sensors locations. Sink moves through the edges where each edge is associated with a cost and a set of labels. Cost is the Euclidean distance between nodes and the label set indicates the nodes whose transmission range intersect with the given edge. Mobile sink has to select the shortest path whose label set consist of more number of sensor nodes. This label covering problem is NP-hard and an approximation algorithm was used to solve it. This approach reduced the data collection delay together with energy consumption. For further improvements in energy consumption and delay, in [76, 77], multiple mobile sinks are used for data collection along the shortest path.

Direct data collection from all nodes is impractical in some cases with tight delay requirements. Sensor nodes suffer from buffer overflow due to large delay. Rendezvous based approaches were proposed to address these problems. Here some nodes will be selected as rendezvous points (RPs) and the sink only needs to visit this RPs for data collection. Other nodes will forward their data to these RPs in an energy efficient way. In [78], two algorithms are developed here for RP selection, which are RPCP (RP selection for constrained path) and RPUG (utility-based greedy heuristic). RPCP finds the optimum data collection points for the mobile element moving in a constrained path and RPUG finds the best RPs based on utility. The drawback of RPUG is that it does not balance the energy consumption rate of sensor nodes to improve the network lifetime. In [79], RDFT (Rendezvous design for fixed track) and RDVT (Rendezvous design for variable track) algorithms are proposed for the selection of RPs. First one is RDFT which is for mobile sink with a fixed track. RDFT finds the shortest tour for a mobile sink based on MST (Minimum spanning tree). Cruskal algorithm is also used here for finding the optimum MST and sink tour. RDVT finds the sink tour for variable track. A drawback of RD-VT is that traversing the SMT in preorder leads to the selection of RPs that result in long data forwarding paths to sensor nodes. In [80, 81], a cluster based algorithm is proposed for rendezvous point based data collection. Here the cluster heads will act as rendezvous points. Cluster heads are selected in such a way so as to minimize the tour length of the mobile sink. In [82], an approximation algorithm named RPS-LB (rendezvous point selection with load balancing) is used to find an optimal solution for the mobile sink's trajectory planning.

In [83], the sensor network is partitioned into many clusters and the mobile sink will schedule the data collection based on this partitioned structure. Mobile sink will collect data from the nodes according to their distance from the sinks current position. In [84], zone division hierarchical multiple clustering approaches with multiple moving collectors is proposed. Here the network is divided into different zones and from each zone a master node is selected based on the residual energy. A moving collector is assigned in each zone for collecting data from master nodes for delivering it to the sink. This system prolongs the network lifetime and reduces the data collection latency compared to the systems with no mobile collectors. In [85] the mobile sink uses a biased random walk model to estimate its next position and a rendezvous point selection with splitting tree technique is used to find the path to be followed by the mobile sink for data collection. Together with the optimal path selection, reliability is provided with three techniques such as data encoding, communication and data decoding. Sensor node encode the data using RS coding, transmit it to the mobile sink and the mobile sink will decode the messages to reconstruct the original one. All these techniques helped to improve the energy efficiency as well as reliability. Weighted rendezvous planning is proposed in [86]. Here RPs are selected based on its weight, that depend on its hop distance from the sink and the number of neighbors. Highest weighted node will get higher priority during RP selection. WRP enables the sink to collect data within a given deadline besides conserving the energy. WRP reduces energy consumption by 22% and increases network lifetime by 44%, as compared with existing algorithms.

IV. CONCLUSION

This survey presents various techniques used for improving the energy efficiency of wireless sensor network. Data collection process is the main source of energy consumption. Clustering, collision free protocols, data reduction techniques and mobility based methods are well suited for solving these problems in wireless sensor network. Clustering divide the network into many parts and cluster head will collect the data from other nodes in an energy efficient way. To reduce the collision of data packets and to avoid unnecessary energy expenditure during the active period of sensor nodes, duty cycling based MAC protocols is proposed. Data reduction techniques helped to reduce the amount of data to be transmitted so that the energy needed to transmit the original data can be saved. Mobile nodes can roam around the network for collecting data so as to reduce the multihop transmission from the nodes to the sink. Direct and rendezvous based approaches are proposed which consider both the packet delay and energy consumption into account.

REFERENCES

[1] I. F. Akyildiz, W. Su, Y. Sankarasubramaniam, and E. Cayirci, "Wireless sensor networks: A survey," Computer Networks., vol. 38, no. 4, pp. 393–422, 2002..

[2] I. Bekmezci and F. Alagz, "Energy efficient, delay sensitive, fault tolerant wireless sensor network for military monitoring," Int. J. Distrib. Sens. Netw., vol. 5, no. 6, pp. 729–747, 2009.

[3] L. Yu, N. Wang, and X. Meng, "Real-time forest fire detection with wireless sensor networks," in Proc. Int. Conf. Wireless Commun., Netw. Mobile Comput., Wuhan, China, vol. 2, pp. 1214–1217, 2005.

[4] A. Mainwaring, D. Culler, J. Polastre, R. Szewczyk, and J. Anderson, "Wireless sensor networks for habitat monitoring," in Proc. 1st ACM Int. Workshop Wireless Sens. Netw. Appl., New York, NY, USA, pp. 88–97,2002.
[5] J. Zhang, W. Li, Z. Yin, S. Liu, and X. Guo, "Forest fire detection system based on wireless sensor network," in Proc. 4th IEEE Conf. Ind. Electron. Appl., Xi'an, China, pp. 520–523, 2009.
[6] J.Li, P.Mohapatra, "An Analytical Model for the Energy Hole Problem in Many-To-One Sensor Networks, Vehicular Technology Conference, vol. 4, 2721-2725, 2005.
[7] Wendi Rabiner Heinzelman, Anantha Chandrakasan, and Hari Balakrishnan "Energy-Efficient Communication Protocol for Wireless Micro-sensor Networks," Proc. IEEE Transactions on, Proceedings of the 33rd Hawaii International Conference on System Sciences, 2000.
[8] Ali, Dey, Biswas, R,"ALEACH: Advanced LEACH routing protocol for wireless microsensor networks,"in proc.IEEE International conference on electrical and
computer engineering, pp.909-914, 2008
[9] Seema Band yopadhyay and Edward J. Coyle, "An Energy Efficient Hierarchical Clustering Algorithm for Wireless Sensor Networks," Proc. IEEE Transactions on, Wireless Sensor Network, INFOCOM 2003.
[10] Avinash Sridharan and Bhaskar Krishnamachari, "HEED: A Hybrid, Energy-Efficient, Distributed Clustering Approach for Ad Hoc Sensor Networks," Proc. IEEE Transactions On, Mobile Computing, Vol. 3, No. 4, 2004.
[11] Mao Ye, Chengfa Li, Guihai ChenlandJie Wu, "EECS: An Energy Efficient Clustering Scheme in Wireless Sensor Networks," Proc. IEEE Transactions on, Wireless Sensor Network, 2005.
[12] Dajin Wang, "A Graph-Center-Based Scheme for Energy-Efficient Data Collection in Wireless Sensor Networks," Proc. IEEE Transactions on, Mobile Computing, 2006.
[13] Selvadurai and Sukunesan, "An Energy-Efficient Clustering Algorithm for Multi-hop Data Gathering in Wireless Sensor Networks," Proc. IEEE Transactions on, Journal of Computers, Vol. 1, No. 1, April 2006.
[14] Guihai Chen, Chengfa Li, Mao Ye and Jie Wu, "An Unequal Cluster-based Routing Protocol in Wireless Sensor Networks,"Proc. IEEE Transactions on, Wireless Networks, Vol.15, No.2, pp.193-207,2007.
[15] A. Allirani, and M. Suganthi, "An Energy Efficient Cluster Formation Protocol with Low Latency in Wireless Sensor Networks," Proc. IEEE Transactions on, International Science Index Vol. 3, No. 3, 2009.
[16] Samer A. B. Awwad, CheeKyun Ng and Nor K. Noordin, "Cluster Based Routing Protocol with Adaptive Scheduling for Mobility and Energy Awareness in Wireless Sensor Network," Proc. IEEE Transactions On, Proceedings of the Asia-Pacific Advanced Network , Vol .30 , pp. 57-65, 2009.
[17] Gurpreet Singh Chhabra, Dipesh Sharma, "Cluster-Tree based Data Gathering in Wireless Sensor Network," International Journal of Soft Computing and Engineering. (IJSCE) ISSN: 2231-2307, Volume-1, Issue-1, 2011.
[18] Zhenzhong Huang and Jun Zheng, "A Slepian-Wolf Coding based Energy-Efficient Clustering Algorithm for Data Aggregation in Wireless Sensor Networks," Adhoc and Sensor Networking Symposium, 2012.
[19] Jun Zheng , Pu Wang ,Cheng Li,"Distributed Data Aggregation Using Slepian–Wolf Coding in Cluster-Based Wireless Sensor Networks,"Proc.IEE Transactions on vehicular technology, Vol.59, Issue 5, pp.2564-2574, 2010.
[20] Pu Wang , Cheng Li , Jun Zheng,"Distributed Data Aggregation Using Clustered Slepian-Wolf Coding in Wireless Sensor Networks,"Proc.IEEE International conference on communcations, pp.3616 - 3622 ,2007.
[21] Razieh Sheikhpour and Sam Jabbehdari, "An Energy Efficient Chain-based Routing Protocol for Wireless Sensor Networks," Proc. KSII Transactions on Internet and Information Systems Vol. 7, No. 6, 2013.
[22] K. Arisha, M. Youssef, M. Younis "Energy-aware TDMA-based MAC for Sensor Networks", Proc. IEEE Workshop on Integrated Management of Power Aware Communications, Computing and Networking (IMPACCT 2002), New York City (USA), 2002.
[23] J. Haartsen, "The Bluetooth Radio System", IEEE Personal Communications, Vo. 7, N. 1, pp. 28-36, 2000.
[24] W. Heinzelman, A. Chandrakasan and H. Balakrishnan, "Energy-efficient Communication Protocol for Wireless Microsens or Networks", Proc. Hawaii International Conference on System Sciences (HICSS-34), 2000.
[25] L. van Hoesel and P. Havinga, "A lightweight medium access protocol (LMAC) for wireless sensor networks", Proc. of the 1st International Workshop on Networked Sensing Systems (INSS 2004), Tokyo, Japan, 2004.
[26] S. Chatterjea, L. van Hoesel and P. Havinga, "AI-LMAC: An adaptive, information-centric and lightweight MAC protocol for wireless sensor networks", Proc. of the 2nd International Conference on Intelligent Sensors, Sensor Networks and Information Processing (ISSNIP 2004), Melbourne, Australia, 2004.
[27] Venkatesh Rajendran,Katia Obraczka, J. J. Garcia-Luna-Aceves, "Energy-efficient collision-free medium access control for wireless sensor networks Proceedings of the 1st international conference on Embedded networked sensor systems," Pp. 181 - 192 ,2003.
[28] V. Rajendran, J. Garcia-Luna-Aceves and K. Obraczka, "Efficient Application-aware Medium Access for Sensor Networks", Proc. of the 2nd IEEE Conference on Mobile Ad-hoc and Sensor Systems (MASS 2005), Washington, DC, 2005.
[29] M.Vahabi, M.F.A. Rasid, "Adaptive Data Collection Algorithm for Wireless Sensor Networks," Proc. IEEE Transactions on ,IJCSNS International Journal of Computer Science and Network Security, VOL.8 No.6, 2008.
[30] Gobriel, S., Mosse, D. and Cleric "TDMA-ASAP: Sensor Network TDMA Scheduling with Adaptive Slot-stealing And Parallelism", 29th IEEE International Conference on Distributed Computing Systems, 458-465, 2009.
[31] Wu, D., Wang, G. and Li, "Distributed TDMA Scheduling Protocol Based on conflict-free For Wireless Sensor Networks", International Conference on Intelligent Computing and Integrated Systems (ICICS), pp.876-879.,2010

[32] Shuguo Zhuo , Zhi Wang ,Ye-Qiong Song , Zhibo Wang, "iQueue-MAC: A traffic adaptive duty-cycled MAC protocol with dynamic slot allocation", 10th Annual IEEE Communications Society Conference on Sensor, Mesh and Ad Hoc Communications and Networks (SECON),pp.95-103,2013.

[33] J. Polastre, J. Hill and D. Culler, "Versatile Low Power Media Access for Sensor Networks", Proc. of the Second ACM Conference on Embedded Networked Sensor Systems (SenSys), November 3-5, 2004.

[34] W. Ye, J. Heidemann and D. Estrin, "Medium Access Control With Coordinated Adaptive Sleeping for Wireless Sensor Networks", IEEE/ACM Transactions on Networking, Volume: 12, Issue: 3, Pages: 493-506, June 2004.

[35] T. V. Dam and K. Langendoen, "An Adaptive Energy-Efficient MAC Protocol for Wireless Sensor Networks", The First ACM Conference on Embedded Networked Sensor Systems (Sensys'03), Los Angeles, CA, USA, November 2003.

[36] G. Lu, B. Krishnamachari and C.S. Raghavendra, "An Adaptive Energy-efficient and Low-latency Mac for Data Gathering in Wireless Sensor Networks", Proc. of 18th International Parallel and Distributed Processing Symposium, Pages: 224, 26-30 April 2004.

[37] D. Mirza, M. Owrang, C. Schurgers, "Energy-efficient Wakeup Scheduling for Maximizing Lifetime of IEEE 802.15.4 Networks", Proc. International Conference on Wireless Internet (WICON'05), Budapest (Hungary), pp. 130 - 137, July 2005.

[38] Peng Sun , Xinming Zhang , Zhenzhong Dong , Yi Zhang,"A Novel Energy Efficient Wireless Sensor MAC Protocol",Fourth International Conference on Networked Computing and Advanced Information Management, Vol.1 ,pp.68-72, 2008.

[39] Sthapit, Yong Tae Park ,Jae-Young Pyun ,"Medium Reservation Preamble Based Medium Access Control for Wireless Sensor Network",IEEE 70th conferece on vehicular technology,pp.1-5, 2009.

[40] Li-li Gao, "A Energy Consumption Improvements of S-MAC in WSN", 2011 International Conference on Internet Technology and Applications (iTAP), pp.1-3, 2013.

[41] Weixia Zou, Erfei Wang, Zheng Zhou, Weihua Li, "A contention window adaptive MAC protocol for Wireless Sensor Networks", 7th International ICST Conference on Communications and Networking in China (CHINACOM), pp.566-570, 2012.

[42] Cuixia Wang, Yunli Chen, Yibin Hou, "The Analysis and Improvement of SMAC Protocol for Wireless Sensor Networks", IEEE Ninth International Conference on Mobile Ad-hoc and Sensor Networks (MSN), pp.437-441, 2013

[43] Haigang Hu, Jie Min, Xiaodong Wang, Yu Zhou, "The improvement of S-MAC based on dynamic duty cycle in wireless sensor network", IEEE International Conference on Computer Science and Automation Engineering (CSAE), Vol.1, pp.341-345, 2011.

[44] I. Rhee, A. Warrier, M Aia, J. Min, "Z-MAC: a Hybrid MAC for Wireless Sensor Networks", Proc. ACM Sen Sys 2005, S Diego (USA), November 2005.

[45] Heping Wang, Xiaobo Zhang, Khokhar, "WSN05-6: An Energy-Efficient Low-Latency MAC Protocol for Wireless Sensor Networks ", IEEE Global Telecommunications Conference , GLOBECOM '06. pp.1-5, 2006.

[46] Tamilselvan. G.M, Kiruthika. S, "An energy efficient data aggregation based medium access control protocol using centre at nearest source approach for sensor networks in a lattice topology", International Conference on Computing, Communication and Applications (ICCCA), 2012

[47] D. Chu, A. Deshpande, J.M. Hellerstein, W. Hong, "Approximate Data Collection in Sensor Networks using Probabilistic Models", Proc. of the 22nd International Conference on Data Engineering (ICDE06), p. 48, Atlanta, GA, April 3-8, 2006.

[48] A. Jain, E. Y. Chang, Y.-F. Wang, "Adaptive Stream Resource Management Using Kalman Filters", Proc. of the ACM International conference on Management of Data (SIGMOD2004), Paris (France), pp. 11-22, June 13-18, 2004.

[49] B. Kanagal and A. Deshpande, "Online Filtering, Smoothing and Probabilistic Modeling of Streaming Data", Proc. of the 24th International Conference on Data Engineering (ICDE 2008), Cancún, México, April 7-12, 2008.

[50] C. Alippi, G. Anastasi, C. Galperti, F. Mancini, M. Roveri, "Adaptive Sampling for Energy Conservation in Wireless Sensor Networks for Snow Monitoring Applications", Proc. of IEEE International Workshop on Mobile Ad-hoc and Sensor Systems for Global and Homeland Security (MASS-GHS 2007), Pisa (Italy), October 8,

[51] M. Basseville, and I.V. Nikiforov, "Detection of Abrupt Changes: Theory and Application", Prentice-Hall, Inc. 1993.

[52] A. Jain, J. Y. Chang, "Adaptive Sampling for Sensor Networks", Proc. of the 1st international workshop on Data management for sensor networks (DMSN 2004), pp. 10-16, Toronto, Canada, August 30th, 2004.

[53] M. C. Vuran and I. F. Akyildiz, "Spatial Correlation-based Collaborative Medium Access Control in Wireless Sensor Networks", IEEE/ACM Transactions on Networking, Vol. 14, No. 2, pp. 316-329, April 2006.

[54] J. Zhou, D. De Roure, "Flood Net: Coupling Adaptive Sampling with Energy Aware Routing in a Flood Warning System", Journal of Computer Science and Technology, Vol. 22, N. 1, pp. 121-130, January 2007.

[55] D. Petrovic, R. C. Shah, K. Ramchandran, and J. Rabaey, "Data Funneling: Routing with Aggregation and Compression for Wireless Sensor Networks," In Proceedings of First IEEE International Workshop on Sensor Network Protocols and Applications, May 2003.

[56] T. Arici, B. Gedik, Y. Altunbasak, and L. Liu, "PINCO: a Pipelined In-Network Compression Scheme for Data Collection in Wireless Sensor Networks," In Proceedings of 12th International Conference on Computer Communications and Networks, October 2003.

[57] S. S. Pradhan, J. Kusuma, and K Ramchandran, "Distributed Compression in a Dense Microsensor Network," IEEE Signal Processing Magazine, Volume: 19, Issue: 2, pp. 51-60, March 2002.

[58] J. Kusuma, L. Doherty, and K. Ramchandran, "Distributed Compression for Sensor Networks," In Proceedings of 2001 International Conference on Image Processing,

[59] Jonathan Gana Kolo,S.Anandan Shanmugam ,David Wee Gin Lim, Li-Minn Ang, and Kah Phooi Seng,―An Adaptive Lossless Data Compression Scheme for Wireless Sensor Networks‖ Hindawi Publishing Corporation Journal of Sensors Volume 2012, Article ID 539638, 20 pages.
[60] Imon. S.K.A , Khan. A ,Das. S.K , "EFFECT: An energy efficient framework for data compression in tree-based wireless sensor networks," IEEE 15th International Symposium on A World of Wireless, Mobile and Multimedia Networks (WoWMoM), 2014
[61] Marcelloni. F., Vecchio.M, "A Simple Algorithm for Data Compressionin Wireless Sensor Networks," Communications Letters, IEEE ,Vol.12, Issue: 6 ,pp.411 - 413, 2008.
[62] Bin Cheng, ZhezhuangXu, Cailian Chen, Xinping Guan, "Spatial Correlated Data Collection in Wireless Sensor Networks With Multiple Sinks," Proc. IEEE Transactions on, The Third International Workshop on Wireless Sensor, Actuator and Robot Networks, 2011
[63] Mr. Sandeep.C, Mrs. Manimozhi I, Dr. Jitendranath Mungara, "Clustering Approach for Fast Energy Efficient Data Collection In Wireless Sensor Network," Proc. IEEE Transactions on, International Journal of Computer Science and Mobile Computing, Vol. 2, Issue. 7, July 2013, pg.240 – 246
[64] C.Tharini1 and P. Vanaja Ranjan, "An Energy Efficient Spatial Correlation Based Data Gathering Algorithm for Wireless Sensor Networks," International Journal of Distributed and Parallel Systems (IJDPS) Vol.2, No.3, May 2011.
[65] Shah, R. C., Roy, S., Jain, S., and Brunette, W. 2003. Data mules: Modeling a three-tier architecture for sparse sensor networks. In Proceedings of the 2nd ACM International Workshop on Wireless Sensor Networks and Applications (SNPA 2003).
[66] Jain, S., Shah, R., Brunette, W., Borriello, G., and Roy, S. 2006. Exploiting mobility for energy efficient data collection in wireless sensor networks. ACM/Springer Mobile Networks and Applications 11, 3 (June), 327{339.
[67] Conti, M., Pelusi, L., Passarella, A., and Anastasi, G. 2008. Adaptation and Cross Layer Design in Wireless Networks. CRC Press, Chapter Mobile-relay Forwarding in Opportunistic Networks, 389{418.
[68] H. Jun, W. Zhao, M. Ammar, E.Zegura, C. Lee, "Trading latency for Energy in Wireless ad hoc networks using message ferrying" , Proc. IEEE Per COM Workshop,International Workshop on Pervasive Wireless Networking (PWN 2005) , March 2005.
[69] Jawhar. I, Ammar. M, Sheng Zhang ,Jie Wu ,"Ferry-based linear wireless sensor networks",IEEE Global Communications Conference (GLOBECOM),pp.304-309, 2013.
[70] W. Zhao, M. Ammar, E.Zegura, , "A message ferrying approach for data delivery in sparse mobile ad hoc networks", proc. ACM MobiHoc 2004, Tokyo, Japan , May 2004.
[71] Wang, G., Cao, G., La Porta, T., and Zhang, W. 2005. Sensor relocation in mobile sensor net- works. In Proceedings of the 24th IEEE Conference on Computer Communications (INFOCOM 2005). Vol. 4.
[72] Rao, J. and Biswas, S. 2008. Joint routing and navigation protocols for data harvesting in sensor networks. In Proceedings of the 5th IEEE International Conference on Mobile Ad Hoc and Sensor Systems (MASS 2008). 143{152.
[73] Anastasi, G., Borgia, E., Conti, M., and Gregori, E. 2010. A Hybrid Adaptive Protocol for Reliable Data Delivery in WSNs with Multiple Mobile Sinks. The Computer Journal to appear.
[74] S. Nesamony, M. Vairamuthu, and M. Orlowska, "On optimal route of a calibrating mobile sink in a wireless sensor network," in Proc. 4th Int. Conf. Netw. Sens. Syst., Braunschweig, Germany, Jun. 2007, pp. 61–64.
[75] R. Sugihara and R. Gupta, "Improving the data delivery latency in sensor networks with controlled mobility," in Distributed Computing in Sensor Systems, S. Nikoletseas, B. Chlebus, D. Johnson, and B. Krishnamachari, Eds. Berlin, Germany: Springer-Verlag, 2008, pp. 386–399.
[76] Mirela Marta , Mihaela Cardei,"Improved sensor network lifetime with multiple mobile sinks," International journal on Pervasive and Mobile Computing Vol. 5, Issue 5, pp.542-555, 2009.
[77] Sudha. M, Sundararajan. J, Kavitha. K, "RS scheduled multiple mobile sinks in WSNs with delay constrained approach," Fourth International Conference on Computing, Communications and Networking Technologies (ICCCNT), 2013.
[78] G. Xing, T. Wang, Z. Xie, and W. Jia, "Rendezvous planning in wireless sensor networks with mobile elements," IEEE Trans. Mobile Comput., vol. 7, no. 12, pp. 1430–1443, Dec. 2008.
[79] G. Xing, T. Wang, W. Jia, and M. Li, "Rendezvous design algorithms for wireless sensor networks with a mobile base station," in Proc. 9th ACM Int. Symp. Mobile ad hoc Netw. Comput., Hong Kong, China, May 2008, pp. 231–240.
[80] K. Almi'ani, A. Viglas, and L. Libman, "Energy-efficient data gathering with tour length-constrained mobile elements in wireless sensor networks," in Proc. 35th IEEE Conf. LCN, Denver, CO, USA, Oct. 2010, pp. 582–589.
[81] Jin Wang, Xiaoqin Yang, Bin Li, Sungyoung Lee, SeokheeJeon, "A Mobile Sink Based Uneven Clustering Algorithm for Wireless Sensor Networks,"Proc.IEEE Transactions on, Journal of Internet TechnologyVol.14, No.6, 2013.
[82] Luo Mai1, Longfei Shangguan, Chao Lang, Junzhao Du, Hui Liu, Zhenjiang Li, and Mo Li,"Load Balanced Rendezvous Data Collection in Wireless Sensor Networks ," Eighth IEEE International Conference on Mobile Ad-Hoc and Sensor Systems,2011.
[83] Maryam Ahmadi, Liang He, Jianping Pan, Jingdong Xu, "A Partition-based Data Collection Scheme for Wireless Sensor Networks with a Mobile Sink," Proc. Ad-hoc and Sensor Networking Symposium on IEEE ICC 2012.
[84] Neethu Joy, S.Senthil Kumar, "Efficient Data Collection In Wireless Sensor Networks Using Mobile Elements," Proc. IEEE Transactions on, Journal of Information Technology- IJITME, Vol.1 Issue. 3, March- 2014, pg. 13-24.
[85] P. Madhumathy and D. Sivakumar, "Mobile Sink Based Reliable and Energy Efficient Data Gathering Technique for WSN," Proc. IEEE Transactions on, Journal of Theoretical and Applied Information Technology, Vol. 61 No.1, 2014.

[86] Hamidreza Salarian, Kwan-Wu Chin, and Fazel Naghdy ,An Energy Efficient Mobile Sink Path Selection Strategy for Wireless Sensor Networks IEEE Trans. Vehicular Technology, vol. 63, no.5,(2014):2407-2419.