On demand Multicast Routing in Wireless Sensor Networks

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***Abstract*—The wireless networking environment presents imposing challenges to the study of broadcasting and multicasting problems. Developing an algorithm to optimize communication amongst a group of spatially distributed sensor nodes in a WSN (Wireless Sensor Network) has been met with a number challenges due to the characterization of the sensor node device. These challenges include, but are not limited to: energy, memory, and throughput constraints. The traditional approach to overcome these challenges have emphasised the development of low power electronics, efficient modulation, coding, antenna design etc., it has been recognised that networking techniques can also have a strong impact on the energy efficiency of such systems. A variety of networking based approaches to energy efficiency are possible. One of the well-known approaches is to apply clustering techniques to effectively establish an ordered connection of sensor nodes whilst improving the overall network lifetime. This paper proposes an improved clustering based multicast approach that allows any CH to be a multicast source with an unlimited number of subscribers, to optimize group communication in WSNs whilst ensuring sensor nodes do not deprecate rapidly in energy levels. We review several clustering approaches and examine multicast versus broadcast communication in WSNs.**

***Index Terms*—Wireless Sensor Networks, energy efficiency, multicast, clustering techniques**

I. Introduction

Sensor networks offer a powerful combination of distributed sensing, computing and communication. They lend themselves to countless applications and, at the same time, offer numerous challenges due to their peculiarities, primarily the stringent energy constraints to which sensing nodes are typically subjected. Energy efficiency is crucial because of the scale and application environments in which sensors are deployed [1]. The network topology of WSN affects the network connectivity and organization, hence affecting various performance metrics such as communication, network scalability, reliability, data latency, energy efficiency and network life time [2], [3]. Therefore, current research depicts customized domain-specific WSN topologies for efficient utilization of their constrained resources.

Sensors can be deployed in various applications to sense a phenomenon; these broadly include environmental monitoring, surveillance, and health monitoring. These applications require that sensors are able to organize themselves to enable communication, sense the phenomenon, process the data and report the information back to the base station (BS). This is not easily achieved over a long period of time as sensors may become unavailable due to destruction or reduced residual energy. At this point, the network of sensors would have to re-establish communication routes to the base station. Increased communication amongst sensors as well as with the base station will also reduce the network lifetime [4]. It is therefore vital that communication overheads must be reduced; hence reporting only aggregated values back to the base station. Grouping nodes into clusters will provide aggregation; meaning each cluster has a cluster head (CH) that coordinates its cluster members by aggregating their sensed data and forwarding to other CHs en-route to the base station for analysis [3]. To provide extensive area coverage, a large number of nodes is required. Moreover, to provide a centralised management system of nodes, a clustering algorithm is provided as an effective means to extend lifetime and manage WSN's. Significant attention has been paid to clustering strategies and algorithms, yielding a large number of clustering protocols. Clustering mechanisms in WSNs have been investigated in the past in order to enhance network manageability, channel efficiency and energy efficiency. However, there exists the hot spot problem which causes an unbalanced energy consumption in equally formed clusters [5].

Emerging WSN applications could greatly benefit from multi casting and constitute another field where multi casting can be an effective and efficient technique [6]. Multi casting potentially optimises bandwidth consumption and node resources, when several users simultaneously participate in a communication session [7]. The main design objectives of multicasting mechanisms is to achieve high efficiency in terms of minimizing the number of relaying nodes, minimizing the total transmission power, and maximizing the network lifetime. The use of a set of point-to-point channels to support a virtual multicast environment results in a complex and inefficient process, mainly in wide area networks. The emergence of applications with inherent multicast requirements led to the development of native multicast protocols [8], [9], [10], [11]. Existing solutions for multicast in WSNs are limited because they either support multicast only from a single source node or they limit the multicast group size to constrain memory usage [12]. Also, the inclusion of IP in WSNs has several potential advantages. Based on the multicast approach, it would be desirable to organize the new routes (formed on demand), to route the cluster head data towards the BS, hence able to mitigate the hotspot problems in WSN and also to enhance better performance in terms of connectivity, reliable packet delivery, low latency and life time of the network. Moreover, clustering is indispensable for hierarchical routing or multicasting in WSNs, as multicast protocols can offer several benefits [13]. The paper presents an analysis of existing multicast protocols and current achievements in research with in WSN's. It provides a comprehensive study of multicast routing protocols for WSN's.

The rest of the paper is organised as follows. Section II presents the background and related work, focussing mainly on multicast approach in WSNs and clustering techniques. The proposed idea is presented in detail along with the possible benefits in section III. Section IV concludes the present work and provides the future directions towards integration of our approach with the IP layer.

II. Background and Related Work

Multicast Approach in WSNs

Many possible applications of WSNs exist, including heath monitoring, habitat monitoring, smart homes, etc. There are many cases in which the use of multicast is of great interest. Multicasting in WSNs is an efficient way to disseminate the same data to multiple receivers. Multicast is a fundamental routing approach for efficient data dissemination required for activities such as code updates, task assignment and targeted queries [14]. Due to the unique characteristics of WSN, efficient, reliable and energy efficient multicasting becomes a challenging task. Multicast protocols such as [15], [16], [17] are more efficient and robust than other stateful protocols as they exploit location information available. These protocols build multicast trees using location information and use geographic forwarding to forward packets down the multicast trees. In general, multicasting protocols eliminate redundant re-transmissions by confining the data dissemination to a limited area. However, this comes with the additional cost of overhead to keep the data distribution structure alive. Intuitively, while multicasting is expected to be a more efficient method of data distribution for small group sizes, broadcasting would be more efficient for large group sizes. Thus it is obvious that in multicast communication the management of WSNs may benefit by reducing the number of transmitted packets and also by saving the energy [12], [7].

A purely theoretical analysis of WSN-specific multicast protocols is presented in [18]. Authors in [19], present an implementation of multicast in WSNs. This approach bypasses the memory problem by only supporting base to node multicast. In addition, the protocol itself is a standard multicast approach, requiring periodic subscriptions to avoid expiring nodes. Similar works have been proposed in [20]. Despite the high promise of the location-based protocols, there are few challenges that affect the performance of the network. One such challenge is the existence of hot-spots [5] i.e., when clustering techniques are implemented, CH's nearest to the BS tend to deplete their energy the fastest since they are burdened with heavy relay traffic from the rest of the network in addition to their own intra-cluster traffic share.

Clustering in WSN

Clustering is an important mechanism in multi-hop WSNs for obtaining scalability, reducing energy consumption and achieving better network performance [21]. There has been active research on how best to form clusters, as clustering has proven to improve the network lifetime of sensor nodes [22]. Several approaches for network lifetime improvement exist, which focus on single-hop and multi-hop data transmission clusters. CHs could transmit data directly to the base station (single-hop), or en-route other CHs towards the base station (multi-hop) [2]. This arrangement has a significant implication on the choice of CHs. Because nodes will die off due to loss of energy, the CH role is rotated leading to re-clustering of the network. Popular objectives of clustering, that facilitate meeting the application requirements are:

- Load balancing: Clustering schemes help to prolong the networks lifetime, by reducing energy usage in intra-cluster as well as in inter-cluster communication. It is intuitive to balance the load among them, so as to improve the performance goals [23].
- Network Longevity: For the applications of WSNs in harsh conditions, networks lifetime is a major concern. It is imperative to minimize the energy for intra-cluster communication, when Cluster Heads (CHs) are richer in resources than sensors [24]. Adaptive clustering is also a possible solution for achieving network longevity [25], [26]. It is also ideal to place cluster heads closer to other sensors in its cluster [27], [28].
- Cost of Clustering: Although clustering plays a vital role in topology organization, often, many resources such as communication and processing tasks are needed in the creation and maintenance of the clustering topology. Such costs as the required resources are not being used for data transmission or sensing tasks.
- Increased Connectivity: Inter-CH connectivity is an important requirement in many applications. Connectivity can just be limited to ensuring the availability of a path from every CH to the base station or can also be restrictive by imposing a bound on the length of the paths [29], [30].

The network also benefits from increased throughput; through reduced packet collision and channel contention when clustering techniques are applied [3]. We review the well known clustering approaches LEACH, HEED and UHEED in this paper.

1) Low Energy Adaptive Clustering Hierarchy protocol (LEACH): LEACH is proposed by the authors in [31]. The algorithm elects cluster heads solely based on probability model, adapting to topology changes. Moreover, cluster heads use the single hop communication model to forward packets to the base station. The protocol is organised in a way that data-fusion is used to reduce the amount of data to be transmitted, hence maximizing the lifetime. The role of a CH is rotated; due to energy loss of the CH as it has to transmit aggregated data over longer distances to the base station, when compared to its member nodes. No overhead is wasted in deciding which node becomes the cluster head, as each node is independent of other nodes. Each node calculates the minimum transmission energy to communicate with its cluster head and only transmits with that power level. There is a good chance that a node with a very low energy is elected as the CH, as changing the CH is probabilistic in LEACH. This approach may reduce the network lifetime because LEACH does not consider the energy remains of each node. Hence, a more refined version of LEACH can be found in [32]. The lifetime of the sensor networks is maximized by forming unequal clusters first, and then a new threshold algorithm, based on residual energy, is used to elect cluster heads.

Non CH nodes will select its CH by comparing RSSI of multiple CHs, from where the nodes received advertisements. Elected CHs broadcasts their status using CSMA MAC protocol. CHs create a TDMA schedule for its associated group members in the cluster. When data from all the nodes in the cluster is received by CH, the CH aggregates, compress and transmits to the BS.

2) Hybrid energy efficient distributed algorithm (HEED): Younis et. al [33] proposed HEED in which equal sized clusters are formed with the help of two parameters: residual energy of a node and node degree or the node proximity to its neighbours. HEED does not make any assumptions about network topology, size and distribution or density of nodes. Since prolonging the network lifetime is the main goal, residual energy is used as the first parameter, which allows those nodes with higher residual energy to become cluster heads, thus balancing the overall energy of the network. The second factor intra communication cost, which can be cluster density, allows a node to join a CH with the least number of nodes so as to reduce the load of the intra-cluster traffic on the CH. Once the clustering process is over, the network enters a data transfer phase. Clustering will occur again after some time in order to rotate the role of the CH and thus balance the energy levels in the network. In this phase, each node of a cluster forwards data to the CH which in turn forwards the aggregated data of its members in a multi-hop fashion (CH to CH) till the base station (BS) is reached.

Inter-cluster communication can make use of either single hop or multi-hop forwarding [34]. In single hop forwarding, each CH directly transmits to the BS, which can cause excessive use of energy for the CH furthest away from the BS making them critical nodes. However, in multi-hop clustering, nodes nearest to the BS tend to deplete their energy the fastest since they are burdened with heavy relay traffic from the rest of the network in addition to their own intra-cluster traffic share. Those nodes closer to the BS tend to die earlier than the rest and as a result, sensing coverage gets reduced and network partitioning becomes apparent, defined as the hot spot problem.

3) Unequal Hybrid energy efficient distributed algorithm(UHEED): The authors in [5] attempt to solve the problem of nodes nearer to the base station dying earlier. In HEED, each CH uses the same competition radius [35], irrespective of its distance from the base station, hence on average having the same number of nodes in the cluster.On the other hand, UHEED creates unequal sized clusters based on the distance of the CH from the BS. The further away a cluster head is from the BS, the larger will be its competition radius and hence the cluster size will be bigger compared to those clusters formed nearer to the BS. This overall can improve the network lifetime for multi-hop WSNs which will be shown using simulations. This effectively allows more inter cluster or relay traffic and less intra-cluster communication for nodes nearer to the base station, hence preventing their early death, leading to a more uniform residual energy in the network and improves the network lifetime.

III. Our Approach

Multicast routing poses special challenges compared to unicast routing. To minimise the total number of transmissions used in multicasting, it is crucial to decide when to send a packet through different paths. If a packet is sent to each multicast destination separately, the multicast routing becomes unicast routing and hence leading to large number of transmissions and leads to energy inefficiency. Therefore, it is of prime importance in design of energy efficient multicast protocols when to transmit a packet in multiple routes. Also, at the same time, due to the low power with limited computational capacity, computational complexity must be taken into account.

Based on a multicast approach, we want to be able to organize new routes and form multicast groups, with specific CH's becoming routers in multicast performing the functionality, at the same time in order to send the data to reach the BS via different paths which will balance load, improve energy efficiency, connectivity, reliable packet delivery, low latency, and mitigates the hotspot problem. When clusters have been formed, CHs provide communication paths to the sink. Clustering approaches such as HEED, LEACH and UHEED have fixed paths to route data from CHs to the sink, either in a single-hop or multi-hop environment. Though the role of CHs is rotated for energy efficiency in all three, both HEED and LEACH suffer from the hotspot problem [5]. UHEED mitigates the hotspot issue by creating unequal clusters, allowing the CH closer to the sink to observe less intra-cluster traffic and more inter-cluster traffic. Our technique proposes that whilst unequal clustering is a good idea, we can enhance this approach by electing to use alternatives paths to route data to the sink [36]. These routes can be established on demand or pre-established and stored in the memory of nodes. The benefit of pre-established routes is that the flooding of information at the set-up phase is not repeated, however the maintenance of these routes might lead to increased traffic overheads. CHs need to be aware of all immediate neighbouring CHs, so that a new path can be selected on-demand when a route becomes

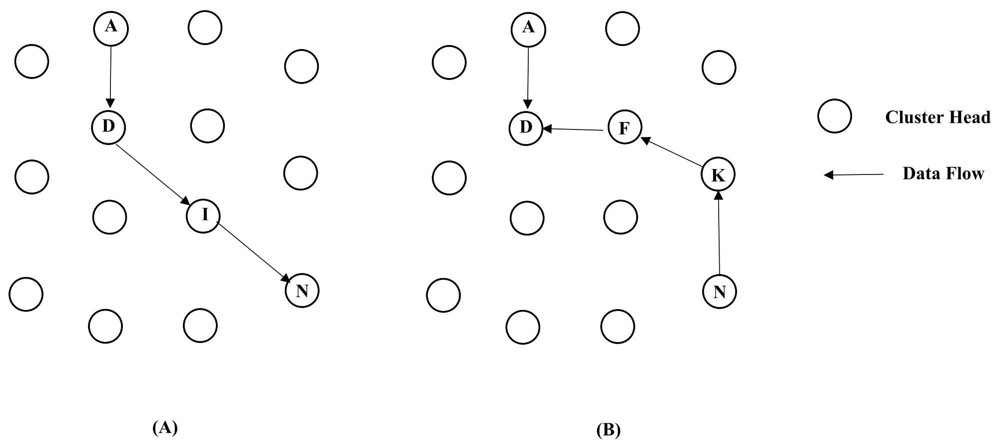

Fig. 1. A) Subscription Process: CH A joins N's multicast; (B) CH N acknowledges A's joining message

unavailable, or location dependent for optimized routing. Each CH must multicast its data to its immediate neighbours rather than broadcast to all nodes [36]. This can be effected at the data-link layer by setting the multicast bit in a multicast packet. The idea of location dependence is addressed by the sensor node's location awareness feature. This feature enables CHs to figure out their closest neighbours. These groups of neighbour CHs can be referenced with a group identification value in a multicast packet. This can also be implemented at the data layer. There are constraints on which node becomes the source of the multicast traffic. Only nodes that have been elected CHs are allowed to generate multicast data for route establishment. The routing tables of CHs will contain all possible next-hop CHs, which can be addressed with a group-id. Enabling CHs to source multicast traffic based on neighbour tables will allow dynamic routes to be formed on demand. To better understand our approach, we consider the PIM-WSN protocol [12] and merge with underlying clustering techniques. We consider some the benefits of PIM and fuse those with our approach, yielding the following benefits:

- Improved energy efficiency: Periodic messaging in WSNs, depletes node energy levels. This shortens the network's lifetime. Our approach addresses this issue by altering the methods for maintaining a multicast membership. They conserve CH energy by preventing CH from timing-out, even if they do not send periodic messages. Rather they consider CH's are unreachable on delivery failures
- Improved reliability: Reliability is achieved by sending a single-hop broadcast message to the neighbour CH's who in-turn acknowledge the message. This can enable reliable routes to be stored in memory.
- Improved memory capacity: From Base to CH multicast has been known to reduce memory usage in WSNs. Only 8-bits are used as CH identifiers. Hence restricting the maximum multicast data size to fit the CH's memory. Other approaches like the Branch Aggregation Multicast (BAM), insert multicast subscription information in all data packets. CHs will no longer be required to send join messages.
- Eliminating periodic messaging: The storing of routes in memory enables our approach protocol to avoid frequent messaging in order to keep routes alive. Instead it deletes this routes only when messages are undelivered.
- Mitigating hot-spots: The hot-spot problem is addressed in UHEED by reducing intra cluster traffic at the node nearest to the sink, to prolong its lifetime. However this does not prevent it from being bogged down with inter cluster traffic. Our approach allows alternative routes to used on-demand. Hence reducing node failure due to hot-spot issues. .

Overview of the design of our approach is presented.

- interested CH initiates the multicast data transfer, sends a unicast join message to the source CH of the multicast containing the source-group pair (S,G).
- source CH receives a valid join message, responds with a join acknowledgement unicast back to the subscriber.
- continues to send the join messages until a join acknowledgement is received or the subscription fails after maximum attempts.
- once the CH receives join acknowledgement, it becomes a subscriber to the specified multicast.
- The multicast source and every CH on the path to the unicast destination of the join acknowledgement stores the address of the next hop towards the destination.
- These CHs are now subscribers to the multicast (S,G), and the information is used to forward multicast data packets sent from that (S,G).

Figure 1 illustrates cluster head "A" joining cluster head Ns multicast. The unicast join acknowledgement messages are indicated by the arrows. Each CH along the path of the join acknowledgement (D, E, and J) updates their local subscription list. For example, cluster head E stores that it must forward multicast packets from N to D. The acknowledgement messages may take different paths (as shown in figure 1). Data flows along the path of the join acknowledgement. Cluster head D then forwards Ns multicast packets to cluster head A. If multiple cluster heads subscribe to Ns multicast, paths to each subscriber are created using the same process. Only one packet is transferred along paths shared by multiple subscribers. This approach can result in optimal, energy efficient and reliable multicasting but is not scalable as it incurs high communication overhead when the number of nodes in the network is very large.

IV. Conclusion and Future work

In this paper, we propose a clustering based multicast approach that allows any CH to be a multicast source with an unlimited number of subscribers, to optimize group communication in WSNs whilst ensuring sensor nodes do not deprecate rapidly in energy levels, hence able to mitigate the hotspot problems in WSN and also to enhance better performance in terms of connectivity, reliable packet delivery, low latency and life time of the network. In our approach, the subscriber CH's are not removed due to time-out, but rather on delivery failure. In case of delivery failure, our approach falls back to unicast routing and signals the CH to rejoin the multicast routing. This gives nodes high confidence that they will remain in the multicast even after the failure of multicast forwarding paths.

It is commonly accepted that the next generation of internet is becoming the "Internet of Things (IoT)" which is a worldwide network of interconnected objects and their virtual representations uniquely addressable based on standard communication protocols. As a result, they are an invaluable resource for realizing the vision of the IoT. In order to encompass the applicability of WSN architecture and to provide useful information any time and anywhere, it is of crucial importance to integrate with the Internet. Realization of these networks will require tight integration and interoperability; however, so far, research has progressed in each of these areas separately. Therefore, it is of crucial significance to develop energy efficient, location- and spectrum-aware cross-layer communication protocols as well as heterogeneous network management tools for the integration of WSNs, cognitive radio networks, mesh networks, and the Internet. To achieve this vision, there is a need for scalable and interoperable networking systems to support the challenging requirements for future internet and web. In the future, we would like to integrate our approach with the IP layer.

References

[1] K. Doddapaneni, E. Ever, O. Gemikonakli, I. Malavolta, L. Mostarda, and H. Muccini, "Path loss effect on energy consumption in a wsn," *International Conference on Computer Modeling and Simulation,*, vol. 0, pp. 569–574, 2012.

[2] I. Akyildiz and M. Vuran, *Wireless Sensor Networks*, ser. Advanced Texts in Communications and Networking. Wiley, 2010.

[3] O. Younis, M. Krunz, and S. Ramasubramanian, "Node clustering in wireless sensor networks: recent developments and deployment challenges," *Network, IEEE*, vol. 20, no. 3, pp. 20–25, 2006.

[4] K. Doddapaneni, E. Ever, O. Gemikonakli, I. Malavolta, L. Mostarda, and H. Muccini, "A model-driven engineering framework for architecting and analysing wireless sensor networks," in *Software Engineering for Sensor Network Applications (SESENA), 2012 Third International Workshop on*, 2012, pp. 1–7.

[5] E. Ever, R. Luchmun, L. Mostarda, A. Navarra, and P. Shah, "Uheed - an unequal clustering algorithm for wireless sensor networks," in *SENSORNETS'12*, 2012, pp. 185–193.

[6] D. Malan, T. Fulford-jones, M. Welsh, and S. Moulton, "Codeblue: An ad hoc sensor network infrastructure for emergency medical care," in *In International Workshop on Wearable and Implantable Body Sensor Networks*, 2004.

[7] R. Silva, T. Camilo, A. Rodrigues, M. Silva, F. Gaudencio, and F. Boavida, "Multicast in wireless sensor networks the next step," in *Wireless Pervasive Computing, 2007. ISWPC '07. 2nd International Symposium on*.

[8] D. Estrin, D. Farinacc, T. A. Helmy, A., A. Deering, M. Handley, V. Jacobson, C. Liu, P. Sharma, and L. Wei, "Protocol independent multicast-sparse mode (pim-sm): Protocol specification," June 1998.

[9] T. Bates, Y. Rekhter, R. Chandra, and D. Katz, "Multiprotocol Extensions for BGP-4," RFC 2858 (Proposed Standard), Internet Engineering Task Force, June 2000, obsoleted by RFC 4760.

[10] W. Fenner, *Internet Group Management Protocol, Version 2*, IETF, Nov. 1997, [Standards Track RFC 2236].

[11] B. Fenner and D. Meyer, "Multicast Source Discovery Protocol (MSDP)," Internet Engineering Task Force, October 2003.

[12] A. Marchiori and Q. Han, "Pim-wsn: Efficient multicast for ipv6 wireless sensor networks," in *2011 IEEE International Symposium on a World of Wireless, Mobile and Multimedia Networks (WoWMoM),*, pp. 1–6.

[13] J. Zheng and A. Jamalipour, *Wireless Sensor Networks: A Networking Perspective*. Wiley, 2009. [Online]. Available: http://books.google.co.uk/books?id=qOPk-NWkgiMC

[14] D. Koutsonikolas, S. Das, H. Charlie, and I. Stojmenovic, "Hierarchical geographic multicast routing for wireless sensor networks," in *Sensor Technologies and Applications, 2007. SensorComm 2007. International Conference on*, 2007, pp. 347–354.

[15] S. Basagni, I. Chlamtac, and V. R. Syrotiuk, "Location aware, dependable multicast for mobile ad hoc networks," *Computer Networks*, vol. 36, no. 56, pp. 659 – 670, 2001, ¡ce:title¿Theme Issue: The Economics of Networking¡/ce:title¿.

[16] K. Chen and K. Nahrstedt, "Effective location-guided tree construction algorithms for small group multicast in manet," in *INFOCOM 2002. Twenty-First Annual Joint Conference of the IEEE Computer and Communications Societies. Proceedings. IEEE*, vol. 3, 2002, pp. 1180–1189 vol.3.

[17] M. Mauve, M. Mauve, H. Fler, H. Fuler, J. Widmer, J. Widmer, T. Lang, and T. Lang, "Position-based multicast routing for mobile adhoc networks," 2003.

[18] R. Flury and R. Wattenhofer, "Routing, anycast, and multicast for mesh and sensor networks." in *INFOCOM*. IEEE, pp. 946–954.

[19] A. Sheth, B. Shucker, and R. Han, "Vlm2: A very lightweight mobile multicast system for wireless sensor networks," in *IEEE Wireless Communications and Networking Conference (WCNC) 2003*, 2003, pp. 1936–1941.

[20] A. Okura, T. Ihara, and A. Miura, "Bam: branch aggregation multicast for wireless sensor networks," in *Mobile Adhoc and Sensor Systems Conference, 2005. IEEE International Conference on*, 2005, pp. 10 pp.–363.

[21] T. Anker, D. Bickson, D. Dolev, and B. Hod, "Efficient clustering for improving network performance in wireless sensor networks," 2009.

[22] A. A. Abbasi and M. Younis, "A survey on clustering algorithms for wireless sensor networks," *Computer Communications*, vol. 30, no. 1415, pp. 2826 – 2841, 2007, ¡ce:title¿Network Coverage and Routing Schemes for Wireless Sensor Networks¡/ce:title¿. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S0140366407002162

[23] M. Younis, K. Akkaya, and A. Kunjithapatham, "Optimization of task allocation in a cluster-based sensor network," in *Proceedings of the Eighth IEEE International Symposium on Computers and Communications*, ser. ISCC '03. Washington, DC, USA: IEEE Computer Society, 2003, pp. 329–336.

[24] M. Younis, M. Youssef, and K. Arisha, "Energy-aware management for cluster-based sensor networks," *Computer Networks*, pp. 649–668, 2003.

[25] T. Moscibroda and R. Wattenhofer, "Maximizing the lifetime of dominating sets," in *19th IEEE International Parallel and Distributed Processing Symposium, 2005. Proceedings.*

[26] R. Khanna, H. Liu, and H. H. Chen, "Self-organization of sensor networks using genetic algorithms," in *Communications, 2006. ICC '06. IEEE International Conference on*, vol. 8, pp. 3377–3382.

[27] E. Oyman and C. Ersoy, “Multiple sink network design problem in large scale wireless sensor networks,” in *2004 IEEE International Conference on Communications*, vol. 6, pp. 3663–3667.

[28] Y. Hou, Y. Shi, H. Sherali, and S. Midkiff, “On energy provisioning and relay node placement for wireless sensor networks,” *Wireless Communications, IEEE Transactions on*, vol. 4, no. 5, pp. 2579–2590, 2005.

[29] F. Dai and J. Wu, “On constructing k-connected k-dominating set in wireless networks,” in *In Proceedings of the 19 th International Parallel Distributed Processing Symposium (IPDPS*, 2005.

[30] S. Bandyopadhyay and E. Coyle, “An energy efficient hierarchical clustering algorithm for wireless sensor networks,” in *INFOCOM 2003. Twenty-Second Annual Joint Conference of the IEEE Computer and Communications. IEEE Societies*, vol. 3, pp. 1713–1723 vol.3.

[31] W. Heinzelman, A. Chandrakasan, and H. Balakrishnan, “Energy-efficient communication protocol for wireless microsensor networks,” in *Proceedings of the 33rd Annual Hawaii International Conference on System Sciences, 2000*, p. 10 vol.2.

[32] C. Xuhui, Y. Zhiming, and C. Huiyan, “Unequal clustering mechanism of leach protocol for wireless sensor networks,” in *Proceedings of the 2009 WRI World Congress on Computer Science and Information Engineering - Volume 01*, ser. CSIE ’09. Washington, DC, USA: IEEE Computer Society, pp. 258–262.

[33] O. Younis and S. Fahmy, “Distributed clustering in ad-hoc sensor networks: A hybrid, energy-efficient approach,” in *Proc. of the 23rd IEEE Intl Conf. on Computer Communications (INFOCOM)*, 2004.

[34] X. Zhao and N. Wang, “An unequal layered clustering approach for large scale wireless sensor networks,” in *2nd International Conference on Future Computer and Communication (ICFCC)*, vol. 1, 2010, pp. V1–750–V1–756.

[35] C. Li, M. Ye, G. Chen, and J. Wu, “An energy-efficient unequal clustering mechanism for wireless sensor networks,” in *Mobile Adhoc and Sensor Systems Conference, 2005. IEEE International Conference on*, pp. 8 pp.–604.

[36] S.-J. Lee, M. Gerla, and C.-C. Chiang, “On-demand multicast routing protocol,” in *Wireless Communications and Networking Conference, WCNC. 1999 IEEE*, 1999, pp. 1298–1302 vol.3.