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Regional Digest Aggregation based on Opportunities in Wireless Sensor Networks

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Abstract*: It is desirable to reduce the amount of data collected in sensor networks to reduce energy consumption and to extend network lifetime while one should extract as much information as possible to allow support for heterogeneous user queries. There have been a number of aggregation proposals, aiming at reducing the amount of data communications within the sensor network, mainly focused on supporting limited and simple types of queries such as SUM, COUNT, AVG, MIN/MAX. Unfortunately, user queries are not limited by these simple types of aggregates and cannot be predicted a-priori. In this paper we propose an aggregation-framework that produces regional digests at a parameter defined granularity such that arbitrary user queries can be supported. Since the success of the aggregation policy greatly depends on the integrated routing mechanisms we evaluate the performance of our approach under alternative routing approaches. Our experimental results suggest at least 3-fold improvement in spatial accuracy at a relatively small expense of increased energy consumption.

Keywords*: Sensor Networks, In-Network Data Management, Aggregation, Adaptive Routing, Energy-Efficiency.

I. INTRODUCTION

Due to advances in sensing equipment, sensor networks are becoming a highly popular tool for various scientific, commercial, and military applications. Environmental monitoring, target tracking, disaster monitoring, earthquake and structural engineering are only a few examples to such applications. Regardless of the particular application, the main objective of sensor networks is to forward observations made in an area to a super node to which users can issue queries. When data collection is initiated with an explicit request prior to data collection, it is referred to as *pull*, whereas when sensor nodes forward their observations without an explicit request, it is referred to as *push* [1]. The success of any sensor network depends on its ability to respond to user queries on the data collected using either pull or push-based approach. In this regard, it is preferable to extract as much useful information from the network as possible, since user queries cannot be predicted a-priori.

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To date, a major focus in sensor network studies has been to minimize the energy consumption in the network as ordinary nodes that are responsible for making observations were typically powered by batteries. Batteries have a limited lifespan, and oftentimes, may be irreplaceable, or not rechargeable. Therefore, for this type of power sources, it is preferable to slow down the rate at which power is drained out of batteries in order to extend the network lifetime. As transmitting one bit over radio is three orders of magnitude more expensive in terms of energy consumption [6], it is desirable to reduce the amount of data traffic during data collection. In this study, we propose an energy efficient regional digest algorithm, R-Digest, that is integrated with routing for efficient data collection, to enable users to issue a wide-range of spatial queries after data collection. Using a tunable aggregation parameter, we are able to trade-off between query response accuracy and energy efficiency. We study the impacts of such aggregation granularity for alternative routing policies. Our performance evaluation results suggest that R-Digest has significant potential to produce reasonable approximations for improved query support. We have observed at least 3-fold improvement in spatial query accuracy at a very reasonable increase in energy consumption. The rest of the paper is organized as follows. In section 2 we present our motivation behind R-Digest, the aggregation policy we propose. In section 3 we outline the R-Digest aggregation data structures and query evaluation process. Section 4 presents the highlights from our performance evaluation for various aggregation parameters and routing policies. Finally, we conclude with section 5.

II. RELATED WORK AND MOTIVATION

A. Existing Proposals on Data Aggregation

The main objective of wireless sensor networks is to make observations in the area of deployment and to communicate these observations to users who access and query the collected data. In general, observations made are collected using either a push-based or a pull-based approach [1][17]. In the pull-based approach queries are issued on-demand and are directed to a specific geographic area according to selected information sources [2][3][16]. In the case of push-based approach, on the other hand, data collection is initiated without an explicit request from the clients. Therefore, the types of queries that need to be supported are not known a-priori. In this respect, original data should be maintained as much as possible such that arbitrary queries that might arrive later can be supported. In the following we discuss representative issues related to data access.

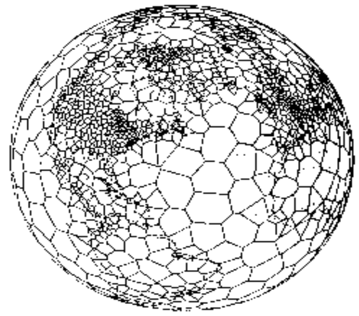
Data aggregation, combining messages from multiple nodes along the routing path, is a popular tool to reduce the amount of data that needs to be communicated. So far, there have been a number of attempts for using data aggregation. Routing protocols such as LEACH [4] or PEGASIS [5] are well-known examples that have considered the possibility of such aggregation. However, a large number of data aggregation policies assume that all data collected is perfectly compatible and can be reduced without any loss during aggregation. For instance, Lindsey et al. [5] have made the assumption that any two messages received at any node can be combined to a single message. In this study, we refer to such aggregates as *singleton aggregates* as they aim at producing a single aggregate value for the whole network. Q-Digest [6] proposes an attempt to acquire more detailed information from the sensor network using histogram-based digests in the network. However, histogram-based digests are focused on a particular aggregation function and are not sufficient to respond to arbitrary queries. Synopsis Diffusion [7] is a recent study that defines a framework for aggregates, yet it focuses on simple functions such as SUM, COUNT, AVG, MIN/MAX. A thorough survey on the basic techniques for data aggregation can be found in [9]. Recently, researchers are more concerned with techniques for scheduling the deployment of the data aggregation process so that the query processing time can be minimized [10][11][15].

Although spatial correlation has been considered in some work such as [12], in essence, none of existing solutions provide sufficient detail to respond to spatial (location dependent) queries which are the most common query types for expert applications. Examples can be in the form "*What was the pressure measured in the region that has reported the lowest temperature?*", or "*What is the chemical dispersion rate at the southeast quadrant of the lake*?" etc.

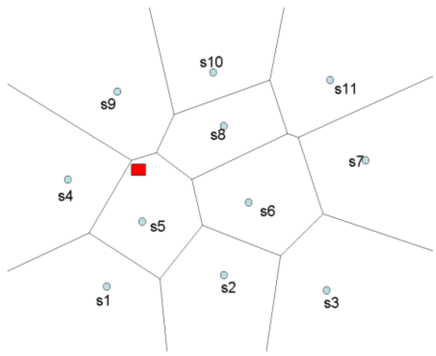
B. Motivation: Responding to Spatial Queries

For a moment, let us assume that there are no resource limitations in the network and *all* of the observations can be reported to data collection points. Even in the case where all individual observations are available at data collection points, query responses can still need some processing. In a sensor network application, only discrete points can be measured while queries can be directed to any point in the region. In such a case we need to extrapolate the measured readings to the other geographic areas. In this regard, one approach used is based on Voronoi diagrams.

In fig. 1, an example scenario is depicted where 11 sensors are deployed in a field represented by small circles. These represent a superset of the discrete points we can obtain an observation from the field. The small rectangle represents a point of interest for a user query. As demonstrated, the user queries are not limited to the discrete data points collected from the field. In this regard different approximation policies are possible. In the figure, each sensor reading is assumed to apply to all points that are closest to its location in comparison to any other sensor location. In other words, for any point of interest for a particular query, we assume that the closest reading applies.



(a) Voronoi Diagram of the Earth, Dividing the Surface into Cells



(b) A Sample Scenario Using 11 Sensors Deployed in the Field

Fig.1. Observations collected by individual sensor nodes are only discrete samples of a continuous space. User queries, on the other hand, can be issued for arbitrary locations in the network. This requires an approximation based on discrete measurements.

In this approach, the correlation among neighboring nodes is completely ignored. For instance, in the fig. 1 assume that the readings at sensor nodes s4, s5 and s9 are 11, 6, and 12 respectively. Using the Voronoi graph approach the query will be replied as 6 ignoring the fact that the two other sensors that are close-by have significantly higher readings.

C. Implications for Large Scale Deployments

Large-Scale deployments of sensor networks include extremely large number of sensors that span a wide geographic area. As an example, PLASMA (PLAnetary Scale Monitoring Architecture) [2] is an interdisciplinary project that aims at an integrated architecture of heterogeneous sensor networks in highly distributed environments. In large scale deployments, even if it was possible to obtain all of observations, it still is not preferable to do so due to the enormous amount of data that would exceed the processing capacity of the servers. Therefore, we try to push data processing closer to the source, the sensor node itself. This would not only reduce energy consumption in the network, but also help optimize query processing cost at the data collection points. As a result, a great deal of approximation is expected while collecting data to respond to individual queries.

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Yet it is not possible to accurately predict user queries that will arrive later. In short, it is not preferable to trade-in data expressiveness at the expense of energy optimizations. Previous aggregation approaches aim at optimizing the energy consumption in the network at the expense of only being able to reply only limited queries. For large-scale deployments of sensor network, we need to pay particular attention to the trade-off between efficiency and query response accuracy.

III. R-DIGEST

The main objective of R-Digest is to allow spatial content in the aggregates being created such that arbitrary queries can be supported. For this purpose, we first analyzed the most descriptive and efficient way to reply to point queries that are targeted to a small area as demonstrated in fig. 1. Due to inherent ambiguity in combining data from multiple sources, we use an opportunistic approach that exploits the correlated nature of sensor readings.

In R-Digest we define a range of impact around each sensor node during the network setup phase. For simplification in the data structures, and thereby in the ordinary node processing, we define this region to be a perfect square defined as a bounding box around the sensor node [1]. Alternative definitions are, of course, possible provided that ordinary sensor processing is efficient. A bounding box is defined by a set of two points, the low, i.e., southeast, and the high, i.e., northwest, point. The size of the bounding box has a default value of *area covered/ # sensors* and can be extended or shrunk according to the certainty level of a reading.

Each node reports an observation in the form:

<*value, min_X, min_Y, max_X, max_Y, first_time, last_time, cnt* >

where *value* is the specific reading being reported, (*min_X, min_Y)* is the lowest and (*max_X, max_Y)* is the highest coordinate within the bounding box, *first_time* is the time stamp of the earliest observation, *last_time* is the time stamp of the latest observation represented in the record (initially *first_time* and *last_time* are the same), and *cnt* is the total number of nodes that contribute to this reporting (initially 1). Obviously, it is possible to extend the data structure to include additional statistics, e.g., the minimum, the maximum etc. readings in the field[2].

In fig. 2, we revisit the example scenario with 11 sensors deployed in the field. Assume that the initial bounding box size is determined to be 4 and node s1 is located at coordinate (5,6). This sensor will then report its individual reading of 9 at time 2 with the record < 9, 3, 4, 7, 8, 2, 2, 1 >. In the figure, we annotate the figure with current data communications taking place. An edge between two nodes suggest that the data record of the node is forwarded over the node that it is connected to. For instance, node s1 will forward its record over node s5.

[1] We have observed that for skewed deployments heterogeneous box sizes provide a finer granularity in aggregates.

[2] In the rest of the discussion, we limit the definition to the average reading for simplification.

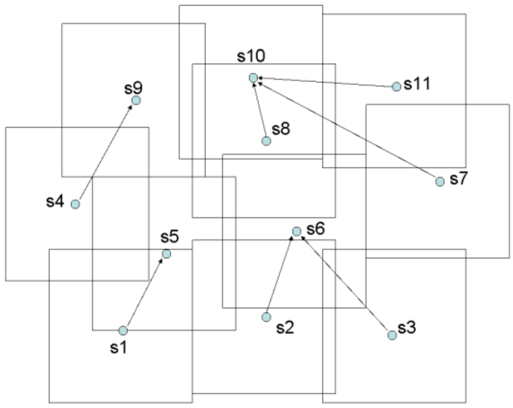

Fig. 2. Each Node Reports its Observation Using A Bounding Box Using Homogeneous Box Sizes. in the Figure A Snapshot of Current State of Routing, in Around, is Also Depicted

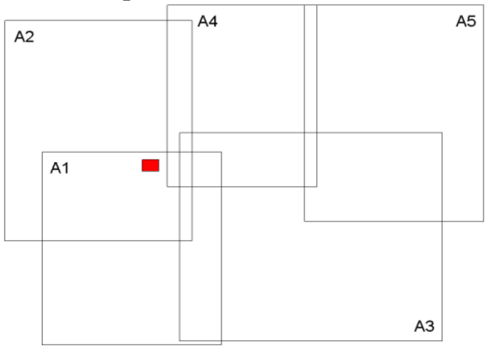

Fig. 3. Data Aggregation, Using A Parameter of 2, Results in 5 Aggregate Records, rather than 11 Individual Observations, to be Collected After Observations are Forwarded Using the Depicted Paths in Fig. 1. Spatial Queries Will be Replied Based on the Resulting Aggregates

During routing, multiple readings will be combined in a single record according to the aggregation parameter. For instance, when node s1 is forwarding its observation over node s5 whose initial reading is < 7, 4, 4, 8, 10, 3, 3, 1 > the two readings can be aggregated. For an aggregation parameter of 2, such that the maximum bounding box for aggregates is allowed to be as large as twice the original size, the aggregate record A1 will look like < 8, 3, 4, 7, 10, 2, 3, 2 > suggesting that two observations are aggregated in the region with an average reading of 8. In fig. 3 we plot the aggregates generated from 11 individual readings as a result of the routing depicted in fig. 2. In this example 5 aggregate records were generated out of 11 records using an aggregation parameter of 2. As demonstrated in this example that the size of the aggregated message at a particular node is not limited to one record. In particular, node s10 has received three records in addition to its own, yet it cannot reduce the four observations down to one due to the restriction on the aggregation parameter. The specific number aggregate records depend on the arrival time of observation and the routing policy being applied. For instance, for the same topology presented in fig. 2, it is possible to reduce the number of aggregates down to 4 using alternative routing approaches.

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As demonstrated a major question in data aggregation is the impact of such aggregation when combined with data routing in the network. In particular, routing policy has a direct impact on the effectiveness of the aggregation. In the experiments we study the impact of alternative routing policies in terms of data aggregation. In particular, we study a traditional routing protocol that is designed independent of the data collection pattern. We then focus on a routing policy FHTL (First Hop Then Leap) based on opportunistic routing [8][13][14] that takes data generation pattern into account. FHTL adapts routing paths and data transfer according to data generated.

Data collection using the described integrated routing and aggregation will result in a number of aggregate/individual records. Once such observations are extracted from the sensor network itself, no further aggregation is applied at the data collection point since these nodes do not have resource constraints that the ordinary sensor nodes have. At this point, the focus shifts to the flexibility of the data structure for various queries rather than the cost of data collection. In this regard, it should be possible to reconstruct the area covered by sensor nodes to approximate the original network readings.

For this purpose, we keep records organized by an index that will enable arbitrary spatial query processing. For instance, to reconstruct the reading within the marked query region in fig. 3, ***we will retrieve the records for A1 and A2*** as they include this region, and report the weighted average of the two aggregates. As a result, the query response will be a function of four individual readings in contrast a single reading as in fig. 1. For regions that overlap with multiple regions the procedure works without additional complexity based on the weighted coverage of the area. Using the alternative spatial data structures, it is possible to provide the user interface with the complete value distribution based on collected data for continuous monitoring of the area.

As can be easily seen by this example, unlike singleton aggregation techniques, in R-Digest the approximation error in the regional query response is limited to that within the close neighborhood rather than the complete network. A major question we analyze for performance evaluation is the impact of such approximations. In the next section we provide results from our experiments.

IV. PERFORMANCE EVALUATION

In order to study larger scale networks than our accelerators can enable, we have implemented a simulator using the C++ programming language to evaluate the performance of our algorithm. We compared our algorithm to Synopsis Diffusion [7] modeled for the perfect average function with unique counting properties. These approaches have their own multi-hop routing schemes. A major question we examine is the impact of routing on data collection and energy efficiency. For this reason, we adapted two approaches for comparison:

As the base case, *R-Digest(L)*, we apply LEACH [4] routing and form clusters by electing cluster heads based on a probability value that favors the nodes which have the most energy. After the selection of cluster heads, nodes join the heads to form clusters. Cluster heads use long-range transmission to talk directly to the data collection point. Note that alternative descriptions exist that enforce multi-hop routing from cluster heads as well. However, these alternatives are not as efficient due to overuse of neighbor communication which is very costly when aggregation is not possible due to the diversity of data collected. In our experiments we exclude the control message overhead to form and dynamically alter the clusters. Therefore, the results presented are only an upper bound on its performance.

As an alternative routing approach, FHTL (First Hop Then Leap), we start with regular multi-hop routing for a number of rounds after which further aggregation becomes unlikely. Beyond this point, we forward the observations directly to the data collection points using direct communication when necesary without investing in control messages for static organization. This approach is referred to as *R-Digest (FHTL).*

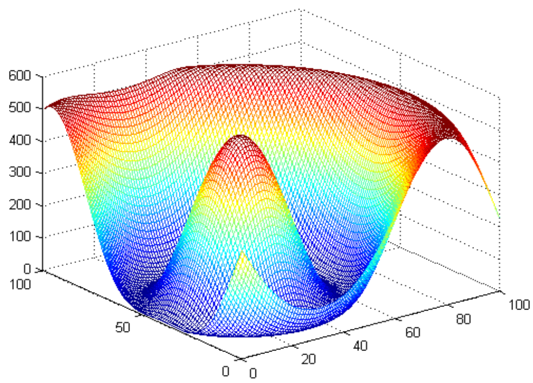

Fig. 4. Original Values in the Field Using a Continuous Function

The main metrics we consider are the accuracy for query support and the overall network lifetime. To evaluate the accuracy of the query responses we used the following strategy. First, we constructed a correlated value space within the complete network as demonstrated in fig. 4. This 3D graph refers to the ideal case if we could deploy sensors so dense that the continuous value space could be represented. In practice, we are able to deploy only a finite number of sensors in an area. In fig. 4, we demonstrate a snapshot of the value matrix to represent the area that is being monitored. This figure represents the continuous function that the sensor nodes are trying to capture at discrete points.

In the experiments, we used 500 nodes randomly distributed in the 500mx500m grid. The data collection point located at southwest corner (0,0). The initial bounding box size is 10. For the first experiment we uniformly generate one packet of data at each node every 10 rounds. A round is the time unit we used in our experiments and each transmission takes one round. At the beginning of the experiment, each node has $2.5*10^6$ nJ of energy.

Each transmission expends an energy of E_{Tx} (k,d) = E_{elec} * k + ε_{amp} * k * d^2 for the transmitting node and E_{Rx} (k,d) = E_{elec} * k for the receiving node. E_{elec} is 50 nJ/bit, and ε_{amp} is 100 pJ/bit/m^2 for the transmit amplifier to achieve an acceptable signal-to-noise ratio.

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When we consider the reconstructed value space based on the aggregated values at the data collection point, a small aggregation parameter provides a very close approximation. For larger values of the aggregation parameter the approximation level increases. As a result, a major question we investigated in our performance evaluation is the trade-offs the parameter setting.

Our main performance metric is the accuracy in query responses based on collected data. In fig. 5, we plot the maximum deviation from the actual values as the aggregation parameter of R-Digest is increased. As expected, the accuracy degrades as this parameter is increased. However, this is at a rather slow rate and the overall benefits are at least 3-fold within the whole range in comparison to the alternative, Synopsis Diffusion. The global aggregate approaches such as SUM, MAX result in significant deviations for regional queries.

A more interesting observation is that the error in regional queries for R-Digest is only slightly affected by alternative routing policies. Interestingly, traditional aggregation policy of LEACH favors regional aggregation which in turn improves accuracy for spatial queries. More sophisticated routing policy of FHTL, even though improves energy savings significantly, as will be analyzed next, introduces additional approximation for neighboring nodes that are part of separate routing paths.

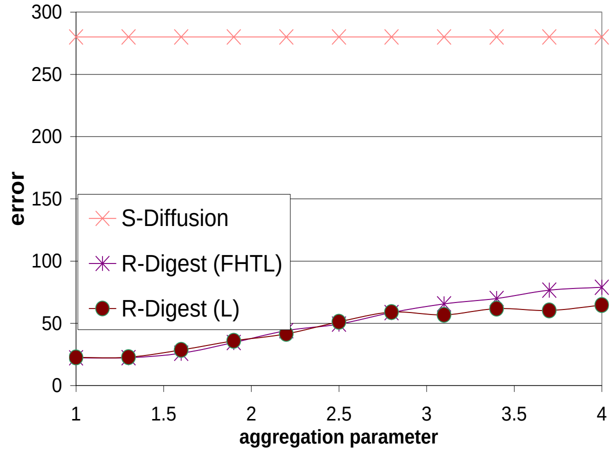

Fig. 5. Deterioration in Accuracy as the Overall Area is Reconstructed

To analyze the impacts of energy consumption we focused on application that require a wide coverage of the monitored area. Traditional energy consumption evaluation approaches focus on the number of nodes still alive in the network. For this purpose, an implicit threshold is used to describe the end of the useful lifetime of the network. For instance, when 70% of the nodes deplete their energy, the network is considered as dead.

In PLASMA we found that the location of the live nodes is as important as the number of such nodes. In particular, having 30% of nodes within 5% of the total area is not as useful as having 30% of nodes alive scattered in a larger area. Based on this observation, we focus on the area covered by live nodes as it defines our remaining monitoring capacity within the deployment area.

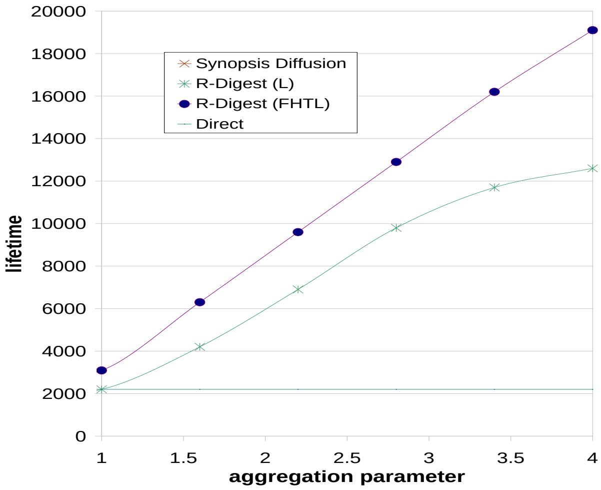

Fig. 6. Network Lifetime Due to the Distribution of Energy Consumption in the Network

In fig. 6, we plot the network lifetime as the aggregation parameter is increased. We define network lifetime according to the distribution of nodes in the network, rather than a scalar number of live nodes. This approach enables us to reflect the distribution of the live nodes in the network such that unbalanced energy consumption schemes can be reflected.

For this metric, we measure the percentage of the area still covered by at least one live node within a radius of 10 and report the time when such coverage falls below 40% of the original deployment area.

In these experiments, we focus on the combined impact of the routing policy and the particular aggregation technique being employed. In fig. 6, we observe that R-Digest when used with LEACH routing starts to level off when the aggregation parameter is increased beyond 3. On the other hand, the lifetime increases linearly for the FHTL routing model. As demonstrated for larger values of the aggregation parameter the benefits of R-Digest (FHTL) will keep increasing linearly. When we consider the energy consumption of Synopsis Diffusion (indicated as the line with lifetime=12000 in fig. 6) we see that for small values of the aggregate parameter, the difference is quite significant. Yet the difference collapses when the aggregation parameter is increased. Based on our results we conclude that R-Digest is a more powerful aggregation policy that allows energy savings in direct ratio of the approximation applied in terms of data collected. As energy constraints seize to be a limiting factor in sensor networks based on renewable energy sources, e.g solar cells, accuracy of collected data can have an even more significant impact in terms of performance.

V. CONCLUSIONS

Data aggregation is a popular approach to reduce the amount of data traffic in the network in order to improve the lifetime of the network. There are two categories of data access for sensor networks; queries on the existing or future observations of sensor networks, and those on the past observations of sensor networks.

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For the second class of queries the nature of user queries cannot be predicted a-priori. As a result, it is desired to maintain as detailed information as possible from sensor observations. In this regard, it is challenging to formulate a successful aggregation function during data collection. In this paper, we propose a new aggregation approach for query processing, R-Digest, for sensor networks. R-Digest produces regional digests during push data collection such that the complete data space can be reconstructed, with some level of approximation, for spatial queries. This approach provides a significant improvement in terms of queries that can be supported using collected data.

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Ethical Approval and Consent to Participate	No, the article does not require ethical approval and consent to participate with evidence.
Availability of Data and Material	Not relevant.
Authors Contributions	All authors have equal participation in this article.

REFERENCES

1. Aksoy D., and Leung M.S. - Pull vs Push: A Quantitative Comparison for Data Broadcast. IEEE Global Telecomunications Conference (2004) Volume 3 1464-1468
2. Aksoy D.- PLASMA: A PLAnetary Scale Monitoring Architecture. Proceedings of ACM international conference on Multimedia (2005) 96-102 https://doi.org/10.1145/1101149.1101164
3. Govindan R, Estrin D, Intanagonwiwat C- Directed Diffusion: A Scalable and Robust Communication Paradigm for Sensor Networks. Proceedings of international conference on Mobile computing and networking (2000) 56-67. https://doi.org/10.1145/345910.345920
4. Heinzelman WR, Chandrakasan A, Balakrishnan H Energy-Efficient Communication Protocol for Wireless Microsensor Networks, IEEE Hawai Int. Conf. on System Sciences (2000).
5. Lindsey S, Raghavendra CS- PEGASIS, Power Efficient Gathering in Sensor Information Systems, IEEE Aerospace Conference Proceedings (2002) 1125-1130 Vol 3.
6. Shrivastava N., Buragohain C., Agrawal D., Suri S.- Medians and Beyond: New Aggregation Techniques for Sensor Networks . Proceedings of international conference on Embedded networked sensor systems (2004) 239-249. https://doi.org/10.1145/1031495.1031524
7. Suman Nath, Phillip B. Gibbons, Srinivasan Seshan, and Zachary Anderson - Synopsis Diffusion for Robust Aggregation in Sensor Networks. ACM Transactions on Sensor Networks (2008). Volume 4, Issue 2, Article No7. https://doi.org/10.1145/1340771.1340773
8. Chen C., Aksoy D., and Demir T.- Processed Data Collection using Opportunistic Routing in Location-Aware Wireless Sensor Networks. Proceeding of International Conference on Mobile Data Management (2006) 150-158.
9. Fasolo E., Rossi M., Widmer J., Zorzi M., In-network aggregation techniques for wireless sensor networks: a survey. IEEE Wireless Communication. Vol 14, Issue 2, (2007) 70-87. https://doi.org/10.1109/MWC.2007.358967
10. Yu B., Li J., and **Li Y.**, Distributed Data Aggregation Scheduling in Wireless Sensor Networks, IEEE INFOCOM 2009,(2009) 19-25. https://doi.org/10.1109/INFCOM.2009.5062140
11. Xiaohua Xu, Xiang-Yang Li, Xufei Mao, Shaojie Tang, Shiguang Wang - A Delay-Efficient Algorithm for Data Aggregation in Multihop Wireless Sensor Networks. IEEE Transactions on Parallel and Distributed System, Vol 22, No1 (2011) 163- 175 https://doi.org/10.1109/TPDS.2010.80
12. Yujie Zhua, Ramanuja Vedanthama, Seung-Jong Parkb. Raghupathy Sivakumara - A scalable correlation aware aggregation strategy for wireless sensor networks. Information Fusion, Volume 9, Issue 3, (2008) 354-369. https://doi.org/10.1016/j.inffus.2006.09.002
13. Parametric Assay of Energy Adept Clustering Protocols for Het-Net Wireless Sensor Networks. (2019). In International Journal of Innovative Technology and Exploring Engineering (Vol. 8, Issue 12, pp. 2146–2155). Blue Eyes Intelligence Engineering and Sciences Engineering and Sciences Publication - BEIESP. https://doi.org/10.35940/ijitee.l2932.1081219
14. Patil, Mrs. Suvarna. S., & Vidyavathi, Dr. B. M. (2022). Application o f Advanced Machine Learning and Artificial Neural Network Methods in Wireless Sensor Networks Based Applications. In International Journal of Engineering and Advanced Technology (Vol. 11, Issue 3, pp. 103–109). Blue Eyes Intelligence Engineering and Sciences Engineering and Sciences Publication - BEIESP. https://doi.org/10.35940/ijeat.c3394.0211322
15. P. H., S., & Kakkasageri, M. S. (2021). An Efficient Information Aggregation Scheme in Internet of Things: Multi Agent based Approach. In International Journal of Soft Computing and Engineering (Vol. 11, Issue 1, pp. 23–31). Blue Eyes Intelligence Engineering and Sciences Engineering and Sciences Publication - BEIESP. https://doi.org/10.35940/ijsce.a3525.0911121
16. KPELOU, M., & Kishore, K. (2019). Lightweight Security Framework for Data Outsourcing and Storage in Mobile Cloud Computing. In International Journal of Recent Technology and Engineering (IJRTE) (Vol. 8, Issue 2, pp. 3405–3412). Blue Eyes Intelligence Engineering and Sciences Engineering and Sciences Publication - BEIESP. https://doi.org/10.35940/ijrte.b2239.078219
17. Nasir, F. M., & Watabe, H. (2020). Validation of the Image Registration Technique from Functional Near Infrared Spectroscopy (fNIRS) Signal and Positron Emission Tomography (PET) Image. In International Journal of Management and Humanities (Vol. 4, Issue 9, pp. 63–69). Blue Eyes Intelligence Engineering and Sciences Engineering and Sciences Publication - BEIESP. https://doi.org/10.35940/ijmh.i0877.054920

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