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CPDA: A conflict-free periodic data aggregation technique in wireless sensor networks

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Abstract In Wireless Sensor Networks (WSNs), sensor nodes are generally placed in different geographical locations. The sensor nodes collect data from environment and they react based on the received query requests. It is a great challenge for sensor nodes to send data periodically to the sink node in a conflict-free way. For this, authors present a Conflict-free Periodic Data Aggregation (CPDA) technique in WSNs. CPDA also works in heterogeneous environment where some of the sensor nodes in a network suffer from less amount of energy. The authors have also presented a mathematical model for the proposed data aggregation technique. The simulation results indicate that CPDA technique works well as compared with the existing approaches. The simulation results of CPDA technique are validated through NS-2 simulations.

1. Introduction

In WSNs, different sensor nodes are deployed in various geographical locations which collect various kinds of data periodically from the environment [1,2]. The sensor nodes collect data based on the different received query requests. Different sensor nodes create a network for communication to send data by forming cluster and in each cluster, a cluster head is chosen based on highest energy label of nodes. The cluster head aggregates the data coming from different sensor nodes in a cluster and then it sends the aggregated data to the sink node. The data aggregation process by a cluster includes the collection of incoming data from different sensor nodes and sending those to the sink node for further processing. As the sensor nodes have very limited battery power, so it is very difficult to send data periodically to the sink node. Therefore, the data aggregation technique is used by a cluster head to enhance the battery life of sensor nodes.

In case of in-network, data aggregation can minimize the bandwidth of the network as well as the energy consumption. Nowadays, wireless cyber-physical frameworks provide real-time support for data collection in WSNs with high data rate [3,4]. There are a few applications like structural health moni-

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toring [5] where response time is very important when emergency occurs [6]. Therefore, some of the applications must support periodic data aggregation within deadline. For instance, in case of a chemical plant control, it is very important to collect periodically various readings such as pressure, temperature. within deadline [7]. Similarly, in case of earthquake detection it is very important to collect various data about damages after certain periods. One major advantage of the periodic data aggregation in real time is that based on the current readings immediate actions can be taken. Another important application of periodic data aggregation is in defense forces. The sensor nodes collect the information about the situation of the field over networks periodically.

To support periodic data aggregation with high data rate, authors propose a conflict-free periodic data aggregation technique. CPDA technique supports conflict-free data aggregation by maintaining δ time between two consecutive data packets. CPDA also works with heterogeneous WSNs where some of the sensor nodes suffer from less amount of energy. Authors then present the mathematical analysis of the proposed data aggregation technique.

The rest of the paper is organized as follows: Section 2 describes the related work. Section 3 describes the proposed periodic data aggregation technique and also the scheduling policy in heterogeneous environment. Section 4 presents the problem formulation of data aggregation technique. Section 5 presents simulation results and analysis. Finally, Section 6 concludes the paper.

2. Related work

Through probabilistic separation, the conflict based protocols can provide supports in real time [8]. To work with congestion, there are several protocols such as rate and admission control were developed. These protocols are known as contention based protocols [9–12]. But, one of the major draw backs of these protocols is that they are not suitable for high data rate applications and also for real-time systems. In [13], authors proposed a SPEED protocol which is based on the geographical routing and sends data packets at uniform velocity. This protocol works with multi-path routing [14]. The major disadvantage of this protocol is that it is a contention based MAC protocol. In heavy load conditions, the throughput is large in case of TDMA protocol with respect to the contention based protocol. There are a few applications that use TDMA protocols support real time but these were developed for single-hop networks. The protocols as proposed in [15,16] are suitable for single-hop networks and they do not support multi-hop networks.

In [17], authors proposed a prioritized MAC protocol in WSNs which is based on the Earliest Deadline First (EDF) algorithm. To avoid channel interference, this protocol uses seven frequencies. In [18], authors proposed a Real-Time Query Scheduling (RTQS) approach which deals with preemptive and non-preemptive, and used for multihop networks. DRAND as proposed in [19] is a TDMA based protocol which supports lower capacity. DCQS [20] is a conflict-free query scheduling approach but it does not work in heterogeneous networks. WirelessHART model as proposed in [21] is a centralized approach and various plannings can be done using this model.

In [22], authors analyzed that in case of a simple one-shot query, the data aggregation problem with small amount of delay is NP-hard. In [3], authors proposed a data management technique in WSNs where different cluster heads collect data from their neighboring nodes and send the aggregated data to the sink via Action and Relay Station (ARS). For this, authors used assembly line scheduling algorithm. But, this approach does not support conflict-free periodic aggregation technique and also does not work with low battery power sensor nodes. The proposed data aggregation technique named that is CPDA works in heterogeneous environment when some of the nodes in the network suffer from less amount of energy which is the limitation of existing works [3,17–20].

3. Proposed periodic data aggregation technique

For periodic data aggregation, let a WSN be represented as a conflict-free graph called $C-graph(N,E)$ where, N represents the set of nodes and E represents the set of communication edges among nodes. The communication edge lies between any two nodes if the two nodes are in the radio range of each other. Let, $n_s \in N$ be a sink node. Let's assume $\wp = \{q_1, q_2, q_3, \ldots, q_i\}$ be a set of queries and $\aleph = \{s_1, s_2, s_3, \ldots, s_j\}$ be a set of source nodes which can be able to answer each query. Let each source node produces a set of $\eth = \{d_1, d_2, d_3, \ldots, d_p\}$ data units. The parent nodes receive data units from the source nodes [22].

Let, t_1 be the time required for receiving one data unit by a parent node for query q_i and let θ_i be the delay for receiving that data unit. Now, let T_k^R be the release time for kth instance then for receiving the answer of that query, and deadline for the sink node will be $\left(T_k^R + \theta_i\right)$. In CPDA, the parent nodes receive data units from the source nodes at different time slots to avoid conflicts and also to reduce end-to end delay, multiple parent nodes receive data unit at the same time slot. For that CPDA maintains at least δ time for receiving two consecutive data units. Fig. 1 shows the example of a C-graph where different parent nodes collect data from various source nodes at different time slots. Some of the nodes receive the data units in the same time slot for reducing the delay. That indicates that CPDA supports concurrent execution. A case may arise for

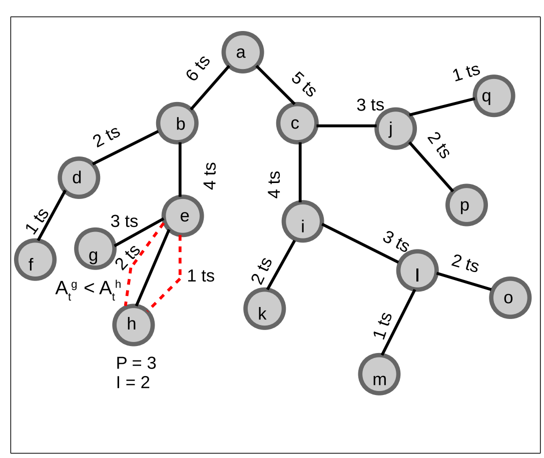


Fig. 1 Example of a C-graph.

a node e in C-graph which collects periodic data. The dash line in C-graph as shown in Fig. 1 indicates that e receives data unit twice from h at every 2 ms. When e receives first data unit then e determines whether it will collect the data unit from g before 2 ms or not. Here, e will give preference to h for time slot 2 as e cannot collect data from g before 1 ms. The different notations used to describe CPDA approach along with their descriptions are given in Table 1.

CPDA supports conflict-free query scheduling when some of the sensor nodes suffer from less battery power. It is very difficult to work when sensor nodes suffer from less amount of energy as if node A sends data to node B but B does not able to receive it due to less amount of energy. The idea behind CPDA is that if the data of node A are received by the next eligible node, the eligible node must receive these data by avoiding the conflict. For this, authors introduce an Interference-Communication Heterogeneous (ICH) graph as shown in Fig. 2. The straight lines in Fig. 2 indicate the communication between two nodes that means when one node sends packets to an another node then the receiver node must be able to receive it. On the other hand, the dotted lines indicate the interference edge that means when one node sends packets to an another node that must be interfered by other transmission. A dotted line with an arrow head indicates a single directional communication whereas a solid line without arrow head indicates a bi-directional communication in an ICH-graph.

Two transmissions $\overrightarrow{ba}$ and $\overrightarrow{le}$ are said to be conflict-free ($ba\|le$) if the given two conditions are satisfied. (1) b, a, l, and e are distinct and (2) be and la do not belong to an interference or communication edge. In the ICH-graph as shown in Fig. 2, the scheduling starts from node b as b is having highest priority among c, d, and e. Now as b suffers from less battery power and hence does not able to communicate with a. So, the child node f initiates to communicate with a at time slot 1. Now, to avoid conflict c, d, and e communicate with a at time slots 2, 3, and 4 respectively. Then, the next child of b that are w and g communicates with a at time slots 5 and 6 as there are no communications in that time slots. w and g are not assigned to time slots 2, 3, and 4 because $wa, ga \nparallel ca$, $wa, ga \nparallel da$, and $wa, ga \nparallel ea$. Now, the children of c are, i, v and h and are assigned to time slots 3, 5, and 6 respectively. Here, i suffers from less battery power and hence i does not able to communicate with c but a case may arise when v cannot be able to assign to that step due to the interference edge $\overrightarrow{dc}$ and so it is assigned to time slot 5.

Table 1 Different notations and their descriptions.

Notations	Definitions
$\wp$	Set of queries
$\aleph$	Set of source nodes
θ_i	Delay for receiving data unit
δ	Minimum time required to receive two consecutive data units
T_k^R	Release time for kth instance
$\sum_{q=1}^{k} D^{c,s}$	Total number of data collected by k parent nodes
$agt()$	Data aggregation function
T^{1,P_q}	Time taken for receiving one unit of data by P_q

Theorem 3.1. *CPDA provides conflict-free data aggregation at all time slots.*

Proof. Let the data units d_1 and d_k execute at same time slots. According to CPDA, these data units are assigned as conflict-free data aggregation if they maintain at least δ time unit that is $(s_1 - s_k) \geqslant (k-1).\delta(x) \geqslant \delta(x)$. Where, s_1 and s_k are the steps and $\delta(x)$ denotes the release time of consecutive data units and $k \geqslant 2$. So, in all slots, CPDA maintains conflict-free data aggregation. □

Theorem 3.2. *CPDA maintains maximum data rate of* $\frac{1}{S(n)\cdot\delta(x)}$ *where, $S(n)$ is the slot size in seconds.*

Proof. According to CPDA, the data unit can be released at $\delta(x)$ slot for avoiding conflict. So, the maximum data rate is $\frac{1}{S(n)\cdot\delta(x)}$. □

3.1. Minimum inter data packets release time (δ)

To calculate the minimum inter data packets release time, we consider an approach as described in [20]. We assume two consecutive data packets as $D^{d,i}$ and $D^{d,j}$. Now, when $D^{d,i}$ is executing and at that time $D^{d,j}$ waits for δ time. Now, if a running data packet cannot be preempted by another data packet then two steps $S(1)$ and $S(\delta+1)$ can run concurrently at the same time slot. So, the data packets $D^{d,j}$ can start after δ steps of data packet $D^{d,i}$ i.e, any slot execution $S^{d,i}(1)\|S^{d,j}(\Delta+z+1)$ where, $z \in (L(D) - (\Delta+1))$ and Δ is the smallest number of execution and $L(D)$ is the total length of data packets. So the minimum inter data packets release time is computed by using Eq. (1).

$$\delta = min[S^{d,i}(l)\|S^{d,j}(l+\Delta+z+1)];\ \forall z \in (L(D) - (l+z+\Delta+1)) \text{ and } l \leqslant L(D) \tag{1}$$

where $S^{d,i}(l)$ denotes any number of steps which do not conflict with another step $S^{d,j}(l+\Delta+z+1)]$.

4. Problem formulation for data aggregation

Let $C = \{c_1, c_2, c_3 \ldots, c_n\}$ be a set containing n number of children of any parent node P_i in WSNs. Now, all children collect data from the environment and send to their respective parent nodes. To avoid conflict, P_i should receive data from all children at different time slots. But, for reducing the end-to-end delay there must be support for concurrent execution. In case of CPDA, it maintains at least δ time for receiving two consecutive data units. The total number of data packets collected by P_i is denoted by $D^{c,s}$ and is computed by using Eq. (2).

$$D^{c,s} = \sum_{i=1}^{b} d_i + \sum_{j=1}^{c} d_j + \cdots + \sum_{n=1}^{m} d_n \tag{2}$$

where $b, c, \ldots, m$ are the number of data packets of children $c_1, c_2, \ldots, c_n$ respectively. Now, total number of data collected by all parent nodes $\sum_{q=1}^{k} P_q$ is computed by using Eq. (3).

$$\sum_{q=1}^{k} D^{c,s} = \sum_{q=1}^{k} \left(\sum_{i=1}^{b} d_i + \sum_{j=1}^{c} d_j + \cdots + \sum_{n=1}^{m} d_n \right) \tag{3}$$

Due to end-to-end delay, P_q may not able to receive exact amount of data within predefined deadline denoted as R_{θ_q,P_q} and is computed by using Eq. (4).

$$R_{\theta_q,P_q} = \left(\sum_{i=1}^{b} d_i + \sum_{j=1}^{c} d_j + \cdots + \sum_{n=1}^{m} d_n\right) - \left(\sum_{i=1}^{b} \theta_i + \sum_{j=1}^{c} \theta_j + \cdots + \sum_{n=1}^{m} \theta_n\right) \quad (4)$$

Now, reducing the end-to-end delay using optimal scheduling policy of CPDA, the amount of data can be computed using Eq. (5).

$$max\left\{\left(\sum_{i=1}^{b} d_i + \sum_{j=1}^{c} d_j + \cdots + \sum_{n=1}^{m} d_n\right) - \left(\sum_{i=1}^{b} \theta_i + \sum_{j=1}^{c} \theta_j + \cdots + \sum_{n=1}^{m} \theta_n\right)\right\} \quad (5)$$

The aim of CPDA was to reduce the delay for receiving data from the source node. So, the objective of CPDA was to maximize the receiving data unit and is possible if

$$\left(\sum_{i=1}^{b} \theta_i + \sum_{j=1}^{c} \theta_j + \cdots + \sum_{n=1}^{m} \theta_n\right) \to 0 \quad (6)$$

CPDA supports concurrent execution by maintaining δ time between two consecutive data units. So, the time taken for receiving one unit of data by P_q is denoted by T^{1,P_q} and is computed by using Eq. (7).

$$T^{1,P_q} = \frac{t_b}{\sum_{i=1}^{b} d_i} + \frac{\delta + t_c}{\sum_{j=1}^{c} d_j} + \cdots + \frac{\delta + t_m}{\sum_{n=1}^{m} d_n} \quad (7)$$

After receiving data unit from the source nodes, P_q aggregates the data and sends to the sink node. We used an aggregation function denoted as $agt()$ for this purpose and is defined in Eq. (8).

$$agt^{P_q} = agt\left(\left(\sum_{i=1}^{b} d_i + \sum_{j=1}^{c} d_j + \cdots + \sum_{n=1}^{m} d_n\right) - \left(\sum_{i=1}^{b} \theta_i + \sum_{j=1}^{c} \theta_j + \cdots + \sum_{n=1}^{m} \theta_n\right)\right) \quad (8)$$

Now, P_q must send data unit to the sink node within deadline. For this, P_q must satisfy the condition as given in Eq. (9).

$$\frac{t_b}{\sum_{i=1}^{b} d_i} + \frac{\delta + t_c}{\sum_{j=1}^{c} d_j} + \cdots + \frac{\delta + t_m}{\sum_{n=1}^{m} d_n} + \frac{x_a}{agt\Big(\Big(\sum_{i=1}^{b} d_i + \sum_{j=1}^{c} d_j + \cdots + \sum_{n=1}^{m} d_n\Big) - \Big(\sum_{i=1}^{b} \theta_i + \sum_{j=1}^{c} \theta_j + \cdots + \sum_{n=1}^{m} \theta_n\Big)\Big)} + \frac{x_s}{agt\Big(\Big(\sum_{i=1}^{b} d_i + \sum_{j=1}^{c} d_j + \cdots + \sum_{n=1}^{m} d_n\Big) - \Big(\sum_{i=1}^{b} \theta_i + \sum_{j=1}^{c} \theta_j + \cdots + \sum_{n=1}^{m} \theta_n\Big)\Big)} \leqslant ((R_1 + \theta_1) + (R_2 + \theta_2) + \cdots + (R_m + \theta_m)) \quad (9)$$

where $t_b, t_c, \ldots, t_m$ denote the time taken to receive the data packets from the child nodes. x_a and x_s represent the time taken for aggregation of data by the parent nodes and time taken for sending the aggregated data to the sink nodes.

$$or,\ T^{R_{cv}} + T^{A,P_i} + T^{S,s_m} = \sum_{i=1}^{m} (R_i + \theta_i) \quad (10)$$

where $T^{R_{cv}} = \frac{t_b}{\sum_{i=1}^{b} d_i} + \frac{\delta + t_c}{\sum_{j=1}^{c} d_j} + \cdots + \frac{\delta + t_m}{\sum_{n=1}^{m} d_n}$

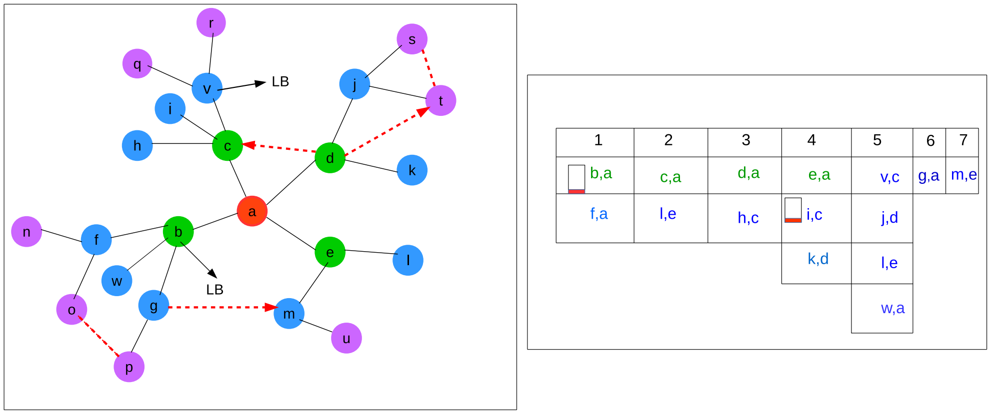
$$T^{A,P_i} = \frac{x_a}{agt\Big(\Big(\sum_{i=1}^{b} d_i + \sum_{j=1}^{c} d_j + \cdots + \sum_{n=1}^{m} d_n\Big) - \Big(\sum_{i=1}^{b} \theta_i + \sum_{j=1}^{c} \theta_j + \cdots + \sum_{n=1}^{m} \theta_n\Big)\Big)}$$ and

$$T^{S,s_m} = \frac{x_s}{agt\Big(\Big(\sum_{i=1}^{b} d_i + \sum_{j=1}^{c} d_j + \cdots + \sum_{n=1}^{m} d_n\Big) - \Big(\sum_{i=1}^{b} \theta_i + \sum_{j=1}^{c} \theta_j + \cdots + \sum_{n=1}^{m} \theta_n\Big)\Big)}$$

5. Results and analysis

The proposed approach CPDA was simulated using NS-2. The parameters used for the simulation is given in Table 2. The 802.11b settings were used where data transmission is 2.2 Mbps. There are various applications such as structural health monitoring used these settings [18]. During simulation, authors used the network range of 750 × 750 which is separated by 85 × 85 grids and there are 100 nodes in the network. For comparison of CPDA with the existing approaches, authors used PAQS [22], DRAND [19], and RTDM [3]. This is because PAQS is a periodic data aggregation technique but is not suitable in case of heterogeneous networks whereas DRAND is a distributed randomized TDMA Scheduling and RTDM is designed for data management system based on the cluster head concept but is suitable for homogeneous networks. Although the proposed CPDA technique is similar to DCQS, the main difference between them is that DCQS does not work not heterogeneous environment whereas CPDA considers the next eligible node by considering the same time slot and provides a periodic data aggregation technique.

A sink node discovers 15 data aggregation query sets. For each query, period, node-ID and the start time of the reply were maintained from the source node. The sink node records each received data from the source node. From simulation results it was found that sink nodes successfully collect data from all source nodes for each period. Authors assumed that a sink node cannot successfully receive data packets from a



(a) (b)

Fig. 2 (a) Example of an ICH-graph where LB indicates Low Battery of Sensor Nodes, (b) Schedule plan of example as given in (a).

Table 2 Parameters used for CPDA approach.

Parameters	Values
Network range	$750 \times 750\text{m}^2$
Number of nodes	100
Data transmission	2.2 Mbps
Data aggregation set for sink	15

source node if it does not receive a query having more than 2 periods. In Fig. 3(a), X-axis represents the average delay and Y-axis represents the number of deployed nodes denoted as N_d. CPDA is compared with a baseline approach PAQS [22] in terms of average delay and success ratio with respect to the number of deployed nodes as shown in Fig. 3(a) and (b) respectively.

From Fig. 3(a), it can be observed that the average delay is high in case of PAQS as compared to CPDA. In case of PAQS, when $N_d = 150$ then average delay is 575 s whereas this is 360 in case of CPDA. This is because, PAQS does not work in heterogeneous environment when some of the nodes in the network suffer from less amount of energy and also does not support conflict-free query scheduling at each slot. The average delay of DRAND and RTDM is higher with respect to CPDA. This is because RTDM processes data with respect to the assembly line scheduling technique where the time for data processing of each node is fixed. If one nodes suffer less amount of energy that will effect the next node and so on. On the other hand, DRAND is a TDMA based scheduling but neither DRAND nor RTDM works in heterogeneous environment. Fig. 3(b), shows that the successful ratio is high when N_d increases in case of CPDA with respect to PAQS. CPDA was also compared with two existing baseline approaches that are RTDM [3], and DRAND [19] in terms of energy consumption with respect to data rate.

Fig. 4 shows the energy consumption with respect to the data rate in CPDA, RTDM, and DRAND. From Fig. 4 it can be observed that the energy consumption is less in case of CPDA as compared to DRAND and RTDM. RTDM also supports conflict-free scheduling at each slot but the problem in RTDM is that it does not support periodic aggregation. However, CPDA along with conflict free scheduling works with low energy nodes at every slot. The disadvantage of the CPDA technique is that it is not suitable when there is require-

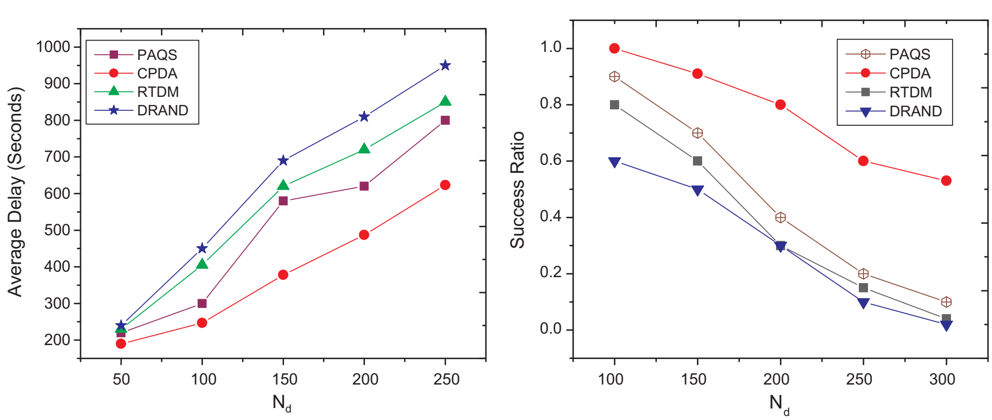


Fig. 3 (a) Average delay with respect to the number of deployed nodes N_d. (b) Success ratio with respect to the number of deployed nodes N_d.

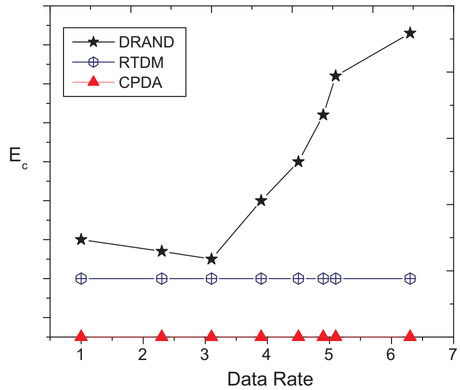


Fig. 4 Energy consumption with respect to data rate.

ment of priority based information which is essential in case of emergency condition.

6. Conclusion

In this work, authors propose a conflict-free data aggregation technique in WSNs named as CPDA. The simulation results indicate that CPDA performs better in terms of different parameters as compared to existing approaches. CPDA supports conflict free data aggregation as well as it works with low battery power sensor nodes in WSNs. In this work, authors also present the mathematical analysis of data aggregation technique. In future, authors would like to develop a priority based periodic data aggregation technique in WSNs.

References

[1] Kanan G, Raja T. Energy efficient distributed cluster head scheduling scheme for two tiered wireless sensor network. Egypt Inform J 2015;16(2):167–74.

[2] Mahajan S, Malhotra J, Sharma S. An energy balanced QoS based cluster head selection strategy for WSN. Egypt Inform J 2014;15(3):189–99.

[3] Sarkar J, Panigrahi C, Pati B, Das H. A novel approach for real-time data management in wireless sensor networks. In: Proc of 3rd international conference on advanced computing, networking and informatics. p. 599–607.

[4] Windmiller J, Wang J. Wearable electrochemical sensors and biosensors: a review. Electroanalysis 2013;25(1):29–46.

[5] Rodgers M, Pai V, Conroy R. Recent advances in wearable sensors for health monitoring. IEEE Sens J 2015;15(6) [p. 3119–3116].

[6] Bertoldo N, Hunter S, Fertig R, Laguna G, MacQueen D. Development of a real-time radiological area monitoring network for emergency response at Lawrence Livermore National Laboratory. IEEE Sens J 2005;5(4):565–73.

[7] Pati B, Sarkar J, Panigrahi C, Tiwary M. ARTQS: an advanced real-time query scheduling approach in wireless sensor networks. In: Proc of international conference on green computing and internet of things (ICGCIoT). p. 219–24.

[8] Chen L, Heinzelman W. QoS-aware routing based on bandwidth estimation for mobile ad hoc networks. IEEE JSAC, Special Issue Wireless Ad Hoc Netw 2005;23(3):561–72.

[9] Lee S, Sriram K, Kim H, Song J. Contention-based limited deflection routing protocol in optical burst-switched networks. IEEE J Sel Areas Commun 2005;23(8):1596–611.

[10] Karenos K, Kalogeraki V, Krishnamurthy S. A rate control framework for supporting multiple classes of traffic in sensor networks. In: Proc of 26th IEEE intl real-time systems symposium. p. 286–97.

[11] Ahn G-S, Campbell A, Veres A, Sun L-H. Supporting service differentiation for real-time and best-effort traffic in stateless wireless ad hoc networks (swan). IEEE Trans Mob Comput 2002;1(3):192–207.

[12] Barry M, Campbell A, Veres A. Distributed control algorithms for service differentiation in wireless packet networks. INFOCOM, vol. 1. p. 582–90.

[13] He T, Stankovic J, Lu C, Abdelzaher T. SPEED: a stateless protocol for real-time communication in sensor networks. In: Proc of int conf on distributed computing systems (ICDCS). p. 46–55.

[14] Felemban E, Lee C, Ekici E. Mmspeed: multipath multi-speed protocol for QoS guarantee of reliability and timeliness in wireless sensor networks. IEEE Trans Mob Comput 2006;5(6):738–54.

[15] Facchinetti T, Almeida L, Buttazzo G, Marchini C. Real-time resource reservation protocol for wireless mobile ad hoc networks. In: Proc of IEEE int real-time systems symp (RTSS). p. 382–91.

[16] Li H, Shenoy P, Ramamritham K. Scheduling communication in real-time sensor application. In: Real-time and embedded technology and applications symposium (RTAS). p. 10–8.

[17] Caccamo M, Zhang L, Sha L, Buttazzo G. An implicit prioritized access protocol for wireless sensor network. In: Proc of IEEE real-time systems symposium. p. 39–48.

[18] Chipara O, Lu C, Roman G. Real-time query scheduling for wireless sensor networks. IEEE Trans Comput 2013;62 ():1850–65.

[19] Rhee I, Warrior A, Min J, Xu L. DRAND: distributed randomized TDMA scheduling for wireless ad hoc networks. In: MobiHoc. p. 190–201.

[20] Chipara O, Lu C, Stankovic J, Roman G. Dynamic conflict-free transmission scheduling for sensor network queries. IEEE Trans Mob Comput 2011;10(5):734–48.

[21] Saifullah A, Xu Y, Lu C, Chen Y. End-to-end delay analysis for fixed priority scheduling in WirelessHART networks. In: Proc of IEEE real-time and embedded technology and applications symp. p. 13–22.

[22] Xu X, Li X, Wan P, Tang S. Efficient scheduling for periodic aggregation queries in multi-hop sensor networks. IEEE/ACM Trans Network 2012;20(3):690–8.