

Performance Evaluation of iSDCP (Improved Statistical Data Collection Protocol) in Cluster Based Wireless Sensor Networks

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ABSTRACT: Wireless Sensor Networks are greatly being deployed in day to day activities ranging from medicinal field, military applications to smart cities. Active research is done to increase the penetration of wireless sensor networks in all the fields to improve the efficiency of the existing systems. A major limitation of wireless sensor networks is its limited battery. To enhance the lifetime of the sensor nodes, various energy efficient techniques like new protocols in the physical layer, Medium Access Layer, routing protocols and cross layered protocols are proposed. One of the important applications in which the wireless sensor nodes are deployed nowadays is in rare event monitoring. Rare events are the events which occur very rarely which needs immediate attention. One such application is wildfire monitoring where the sensor nodes are deployed to sense forest fire. To improve the enhancement of lifetime of the wireless sensor networks in cluster based networks, Statistical Data Collection Protocol was proposed whose results show improved energy efficiency for both the cluster members and cluster head nodes. An improvement to the Statistical Data Collection Protocol is proposed to improve the energy efficiency and thereby to enhance the lifetime of the wireless sensor networks. Further the improvement ensures that the rare event if detected is communicated to the cluster head within the same cycle. The improved Statistical Data Collection Protocol has the same amount of latency to detect the rare event. The proposed protocol is simulated with NS2 discrete event simulator and the simulation results indicate better lifetime than LEACH protocol and the statistical data collection protocol for a static cluster of limited size.

KEYWORDS: Cluster Head; Cluster Member; Low Energy Adaptive Clustering Hierarchy; Statistical Data Collection Protocol; Improved Statistical Data Collection Protocol; Wireless Sensor Network.

I. INTRODUCTION

Wireless Sensor Networks(WSN) are used in almost all fields in our life ranging from smart cities, structural health monitoring, habitat monitoring, hospital healthcare, industry automation to military [1]. The WSN consists of many sensor nodes. Each sensor node is a low power device which contains sensors to sense one or more physical quantity, memory and a radio frequency transceiver to communicate with other sensor nodes along with a processor or controller [1]. Mostly the sensor nodes are powered by a non-rechargeable battery and hence the lifetime of the sensor node is limited by the energy of the non-rechargeable battery [2]. The sensor nodes gather information from the environment and transmit to the base station (BS) based on which further action is taken by the system or the intended user. The energy source for the sensor node is a non-rechargeable battery. C.Nagarajan *et al.* [2,5,8] energy harvesting is done from solar, mechanical, thermal or other sources and vigorous research is progressing in the field of energy harvesting for sensor nodes. In the case of non-rechargeable batteries, the lifetime of the sensor node ends after the battery energy is exhausted. Failure of a sensor node can partition the network or prevent the data from reaching the BS. Limitations of the sensor node in the radio communication range, processing power and battery capacity limits its usage in many

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Vol. 9, Issue 3, March 2020

applications [3]. In many places, the WSN is used in unattended environment where there is no human intervention and the environment may be harsh. Energy efficiency is the main factor deciding the lifetime of the sensor node and the sensor network. The radio transceiver in the sensor node is the highest power consuming subunit in the wireless sensor node.

A. Rare Event Monitoring

One important application in which the WSN is deployed is the rare event monitoring [5]. Rare events occur with a very small probability and occur infrequently during the observation period. One example of rare event monitoring is the sensing of wild fire in forest area [4]. The wildfire may or may not happen during a period of time. However, the forest area needs to be monitored continuously to cater to the need of any wild fire detection. Other instantaneous rare events like perimeter intrusion are not considered. The rare event detection needs to be highly energy efficient unlike other applications for WSN. The rare events considered in this project are the persistent events that stay forever after occurring. For detecting persistent events, the probability of detection is nearly one and the events will be detected by one or more of the sensor nodes. The latency in detecting the event plays a vital role in the application being considered so that corrective action may be initiated and completed.

B. Objective of the Paper

The objective of the research is to enhance the lifetime of the wireless sensor node and thereby enhance the lifetime of the wireless sensor networks deployed in rare event detection [4]. The enhancement in lifetime is estimated by the proposal to reduce the number of data packets transmitted by each of the sensor node detecting rare event. The objective is also to ensure that even after enhancing the lifetime of the sensor network, the time delay in detection and reporting of the rare event is maintained. The objective also includes verification of the proposed protocols for the lifetime enhancement by simulation using a suitable discrete event simulator.

II. LITERATURE REVIEW

A. Clustering

In Low Energy Adaptive Clustering Hierarchy [6] a self-adaptive hierarchical clustering in which nodes are grouped to form a cluster. One of the nodes in a cluster is elected as CH which gathers the data from all the other nodes in the cluster. The CH then fuses the data and transmits the fused data to the BS. The load of the cluster head is reduced by electing another CH after a few numbers of rounds. The cluster head node being the node with higher traffic and higher communication cost, the role of CH is rotated randomly among the cluster nodes. The CH allocates the schedule for the cluster nodes which are low duty cycled and remain in low power modes unless required to sense or transmit or receive data. The results for LEACH show major improvement in the lifetime of the WSN.

In reference [6] C-LEACH in which the base station determines the cluster head based on the GPS location information using a centralized algorithm. MODLEACH is improved version of LEACH protocol [7] in which the cluster head re-election is introduced only if the energy level of the cluster head is lower than the threshold value.

B. Rare Event Detection Techniques

For detecting persistent rare events, the probability of detection is nearly one and it will be detected by one or more of the sensor nodes. The detection delay is an important parameter to be considered as it determines the energy consumption of the sensor nodes for data collection and propagation. The detection delay is varied for different applications and is determined by the application under consideration.

Reference [5] presented a survey for rare event detection and the various propagation methods available in the literature for WSN. A survey of different energy management schemes in WSN was done and a high level taxonomy of energy management schemes for WSN was provided in [8].

International Journal of Innovative Research in Science, Engineering and Technology

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Vol. 9, Issue 3, March 2020

C. Component Deactivation

Component deactivation differs from complete node shutdown by powering down components or subsystems that are not in use, thereby lowering the power consumption of the node. The radio transceiver is the highest power consuming unit of the sensor node and placing the transceiver in low power or sleep mode when there is no radio activity helps in enhancing the lifetime of the node.

In Reference [9], an Address-light Integrated MAC and Routing Protocol (AIMRP) for WSN. In AIMRP, the WSN is organized into concentric tiers with nodes identified based on tiers and not by individual address. The nodes forward the data from the farthest tier away from the BS by multi-hop communication through successive tiers. The nodes in the tiers can be in any one of the different states – sender, listener, receiver or requesting. The nodes are duty cycled when they move to sleep state to conserve energy to prevent idle listening. A source-initiated or sink-initiated general wake-up radio (WUR) based medium access control (GWR-MAC) to avoid idle listening and to improve energy efficiency in short range communication networks [10]. Component deactivation is also considered in the following papers [3], [11], [12].

D. Over Population / Node redundancy

Overpopulation is the method of placing redundant nodes to sense the same event. The nodes are duty cycled and collaborated to detect rare event which improves node failure tolerance level. Equitable Sleep Coverage Algorithm for Rare Geospatial Occurrence (ESCARGO) to detect and notify the occurrence of an event is provided in [5]. The proposed algorithm involves fully distributed duty cycled approach with non-time synchronization with the availability of redundant nodes. References [13], [14] also considered over population approach for detecting events in sensor networks. When more number of nodes are present than that required for coverage of area, efficient duty cycling of nodes ensures coverage of entire area along with increase network lifetime. For this to happen, the number of nodes deployed should be over populated or redundant in nature. Over population approach increases the entire network cost and hence, the strategy is not considered further for implementation.

E. Message Suppression and Data Aggregation

Message suppression and data aggregation play a vital role in extending the longevity of the sensor nodes as the packets communication consumes higher energy. When the number of packets are reduced in the network, the lifetime of the nodes automatically gets extended by employing energy efficient protocols.

When a rare event is detected by more than one node, delivery of only a subset of messages by any of the node confirms the detection of event as reported in [8]. In reference [15] Correlation-based Collaborative Medium Access Control (CC-MAC) in which the spatial correlation of the messages sensed are considered and only the representative message is sent through the network. The CC-MAC filters out the redundant records through Event-MAC (E-MAC) and injects the correlated message into the network which is prioritized by Network-MAC (N-MAC) for route through packets. Sift, a randomized Carrier Sense Multiple Access (CSMA) protocol which uses a fixed size contention window in [16]. In Sift, the spatially correlated messages are transmitted to the BS by suppressing multiple redundant messages reporting the same event. The simulation results report latency reduction for event reporting at the BS by ensuring that at least one node reports the event.

III. STATISTICAL DATA COLLECTION PROTOCOL

One important application among the various fields for WSN is the rare event detection. In rare event detection, various sensor nodes are deployed in the field to sense a specific event based on which further action is initiated. One specific example is wildfire monitoring, in which a number of wireless sensor nodes are deployed to detect the occurrence of forest fire or in specific to detect the high temperature and communicate the value above threshold. The occurrence of forest fire is a rare event which might occur any time during the period of observation. Periodic transmission of information from the sensor nodes to the BS is required to ensure detection of rare event within the constrained time limits.

International Journal of Innovative Research in Science, Engineering and Technology

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Vol. 9, Issue 3, March 2020

Statistical Data Collection Protocol (SDCP) is employed for the improvement of lifetime in the case of rare event detection. For SDCP, clustered architecture for WSN is considered. The various sensor nodes in the network are grouped into various units called clusters. One among the nodes in a cluster is designated as CH which has communication link with all the members of the same cluster and also with the BS. All the CM nodes sense and report the values to the CH which in turn aggregates and transmits to the BS. The clustered architecture is shown in Fig. 1 showing the three clusters reporting to BS. The CH needs to collect data from all the CM in the cluster, aggregate it and report to BS at regular intervals called rounds.

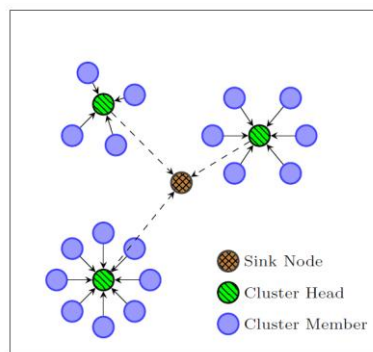


Fig. 1. WSN Cluster Topology

Typical data collection in a cluster is illustrated using packet exchange diagram in Fig. 2.

One cluster member node communicates to the head in one TS and 5 TS are used up for one round. The data transmitted by the CM node is received by the CH node and Acknowledgement (ACK) packet is transmitted by the CH to the corresponding CM node. The state of the node i.e., transmit and receive state are represented by blue and shaded green color respectively. If the rare event is not detected in a round, the data exchanged serves two purposes, first to indicate that the sensor nodes are alive and second to ensure that the data is collected at the CH for statistical purposes. Instead of sending N data, the sensors can send only the statistical data which is of interest at the CH at infrequent intervals. This reduction in the number of data packets will significantly reduce the network traffic.

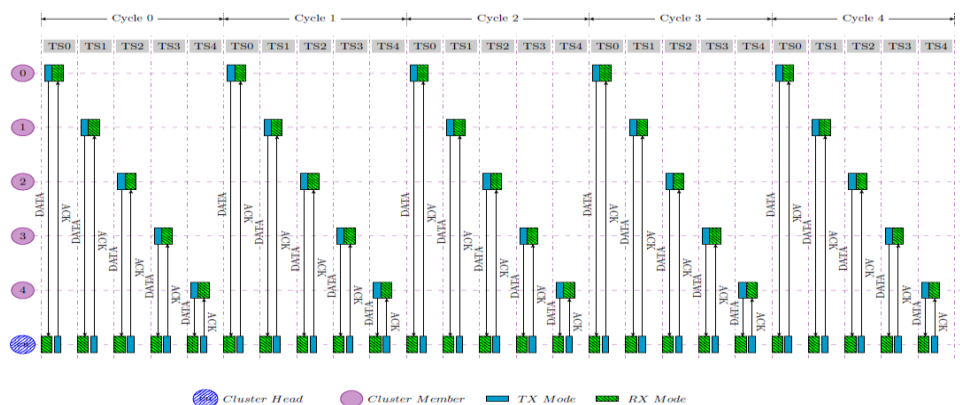


Fig. 2. Typical Data Collection in a Cluster

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

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Vol. 9, Issue 3, March 2020

In SDCP [4] the data collection from the CM nodes during each round is reduced. In each of the rounds, the CH collects data from only one sensor node. If there are N sensor nodes in a cluster excluding the CH, a typical data collection in a SDCP round will involve one statistical data packet transmitted from one CM to CH. In the next round, the next CM node transmits the data to the CH. The Statistical Data Packet (SDP) contains the statistics of interest for the data values that are sensed between two successive transmission and not the entire data. It takes N rounds for the statistical data from N nodes to reach the CH.

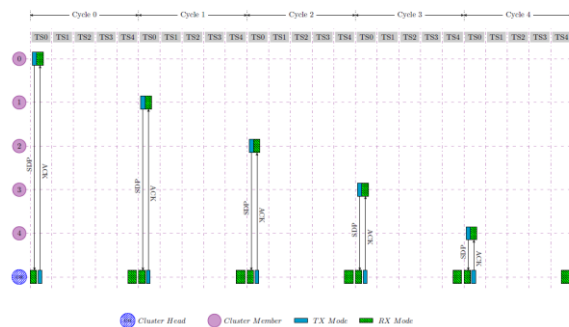


Fig. 3. Data Collection in SDCP

The packet flow diagram during the data collection in SDCP with no rare event is shown in Fig. 3. The CM nodes are scheduled to transmit the SDP only during the zeroth time slot. The SDP and ACK packet exchange for different CM nodes with the CH node is illustrated along with the timeout period for CH at the end of each round.

The packet exchange diagram for when node 1 detects rare event for SDCP is represented in Fig. 4. In cycle 0, node 0 transmits its SDP to CH and receives ACK from CH during TS0. During TS1, node 1 transmits its detected event packet which is not received by any other node. During TS2, TS3 and TS4, node 1 remains in receive state and times out having not received any packets. Towards the end of last time slot TS4, when CH remains in receive state, node 1 transmits its event packet to CH and receives ACK packet. In the cycle 1, node 1 is the scheduled node to transmit in TS0 and gets its event packet transmitted to CH. The CH times out during the second reception phase in cycle 1. The cycles 2, 3 and 4 are similar to cycle 0 in functionality.

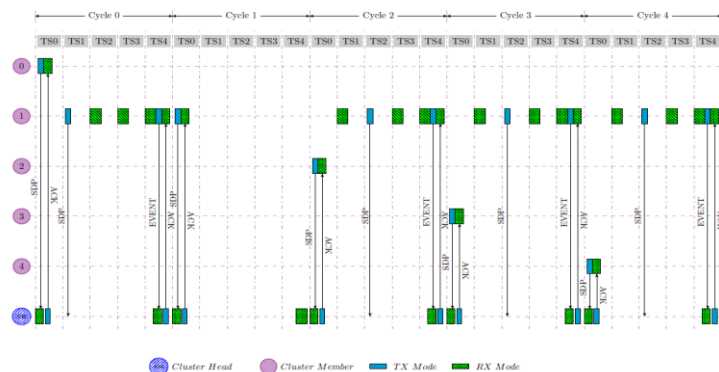


Fig. 4. Rare Event Mode in SDCP

The SDCP incorporates the feature in which the node remains in receive mode in N-2 slots to accommodate the condition in which more than one sensor node has detected rare event. Out of N rounds, if only one CM node detects rare event, then it transmits in one packet for one cycle, and two packets for N-1 cycles and remains in receive state for

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

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Vol. 9, Issue 3, March 2020

N-2 slots for N-1 cycles. If more than one node detects rare event, then to ensure that all rare events detected gets communicated to the CH, the sensor nodes consolidate the rare events data before communicating to CH and eliminate collision at CH.

In the rare event mode, the sensor node consumes more energy during the additional receive and transmit states, which shortens its lifetime. To enable the continuous monitoring of nodes that had detected rare events with utmost priority, another mode called Quick Loop (QL) mode is incorporated in the SDCP. In this mode, the number of transmit and receive states for the node detecting rare event is reduced so that the node's energy consumption is not wasted trying to transmit the event.

The Quick Loop mode is activated if the rare event is sensed by the node continuously for 'n' rounds. The value of 'n' is configurable depending on the size of the cluster and remaining energy in the node. Once the rare event is detected for 'n' rounds, both the CH and CM reach an agreement having entered the Quick Loop mode. In QL mode, the sensor node transmits only once in all the rounds. If it is the regularly scheduled node in the zeroth slot, then there is no change in the schedule. Otherwise, the node is scheduled in the first transmit as in the rare event mode and no receive time slots for the node in the QL mode. In this mode, the rare event packet from the CM node is always acknowledged by the CH node. For this to happen, the CH is scheduled for one more reception for each of the Quick Loop mode apart from the two reception slots of SDCP. This enables the CM nodes to save energy due to removal of additional receive and transmit slots. It is found that the node only transmits once during a cycle which is received by the CH node consistently ensuring proper communication.

IV. IMPROVED STATISTICAL DATA COLLECTION PROTOCOL

In this project, improvement to SDCP is proposed which is termed as Improved Statistical Data Collection Protocol (iSDCP). In this iSDCP, the number of packets exchanged in the network, when no rare event is detected is reduced to half. During the data collection, the sensor nodes transmit data to the CH only in alternate cycles. The nodes do not transmit data in between the cycles but however these cycles are utilized to transmit any rare event detected. This feature of iSDCP ensures that the rare event is always communicated to the CH within the required delay constraint. The data collection during various cycles is illustrated in the Fig. 5.

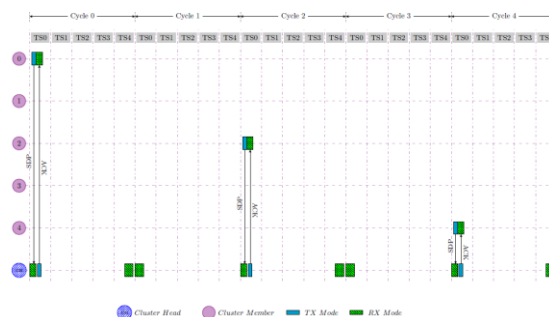


Fig. 5. Data Collection in iSDCP

In iSDCP, data collection is done in alternate rounds. For a cluster with 5 CM nodes and a CH, the data is sent from the CM nodes in 0-2-4-6-8 cycles with the corresponding sensor node ids 0-2-4-1-3 respectively as partially represented in the Fig. 6. It is to be noted that the cycles numbered 1, 3, 5 and 7 are used for exchanging data packets in case the nodes detect rare event. In the proposed iSDCP, the number of data packets exchanged in the network is reduced to half in a given duration. The load of the cluster members as well as that of the cluster head is reduced.

It is to be noted in the figure that the CH node is in the receive state in only one of the time slots in which the cluster member is not scheduled to transmit. This idle listening is to ensure that any rare event detected is communicated to the cluster head and thereby to the base station or the sink node. When there is no rare event detected,

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

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Vol. 9, Issue 3, March 2020

the load on the CH node is reduced by 25% while that of the member nodes is reduced by 50% considering only the number of data packets transmitted.

A. iSDCP Packets

The different types of data packets used in iSDCP are given below. The statistical data packets are used to communicate the statistics to the CH node by the cluster members during the time slot 0. The Rare event packet is used to communicate the rare event detected.

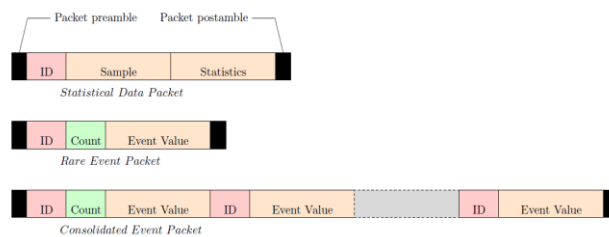


Fig. 6. iSDCP Packet Types

B. Rare Event Mode in iSDCP

In the iSDCP, the alternate cycles are idle in which the CH node remains in the receive state and times out having not received any data from any of the nodes. In case any rare event is sensed by any one of the nodes during the idle cycle, then the EVENT packet is communicated to the CH in the zeroth time slot itself without any collision and the CH node responds with an ACK packet as shown in Fig. 7.

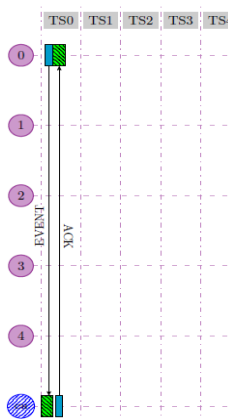


Fig. 7. Rare Event Detected during an idle cycle by node 0 in iSDCP

In case of rare event detection during the inactive cycle, when more than one node detects the rare event, then the provision for communication to CH is made in the iSDCP as shown in the Fig. 8.

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

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Vol. 9, Issue 3, March 2020

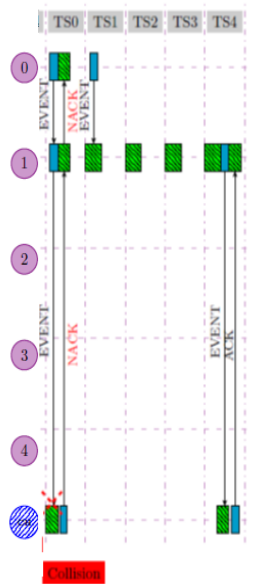


Fig. 8. Rare Event Detection by nodes 0 and 1 in an idle cycle

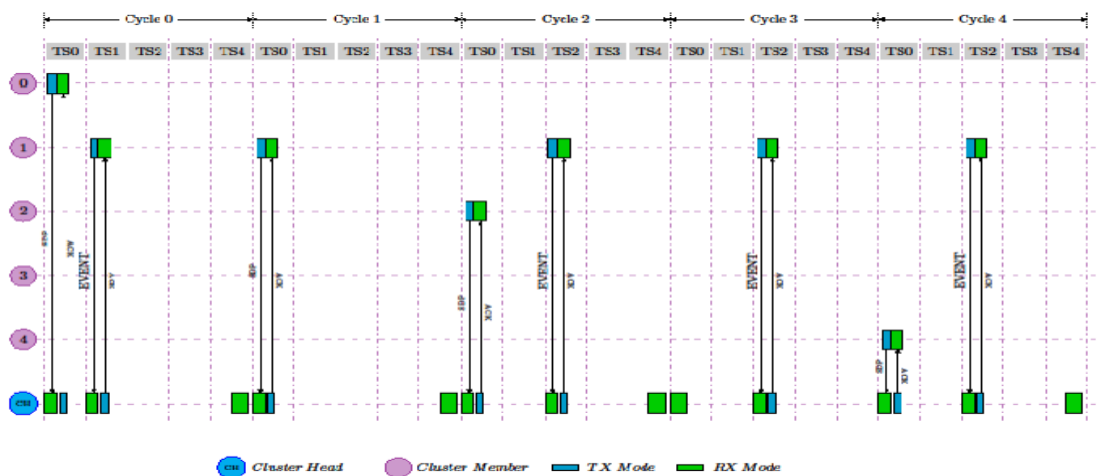


Fig. 9. Quick Loop Mode in iSDCP

From the figure, it is verified that nodes 0 and 1 have detected rare events and both the nodes transmits the event to the CH node during the time slot TS0. Since more than one node had sent the packets, collision results at the CH and the CH node responds with a negative acknowledgement (NACK) packet. Since node 1 is the scheduled node in the timeslot, it remains in the receive mode for the rest of the time slots in the current cycle. Node 1 thus receives the packet from node 0 during TS1 and consolidates with its own event packet. Then the node 1 transmits the consolidated

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

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Vol. 9, Issue 3, March 2020

event packet in the additional time slot in which the CH listens. During the idle cycles, the CH nodes listen twice only when it detects collision in the TS0 to ensure that all the events detected are received by the CH node.

Considering the case in Fig. 8, nodes 0 and 1 have detected the rare event. In TS0, both the nodes send their event packets to CH node which is in the receive mode. Next the CH node experiences collision and hence sends back the NACK packet which is received by both nodes 0 and 1. This NACK packet initiates further transmission and reception by the cluster member nodes. In the remaining time slots, all the nodes except the regularly scheduled node 1 are scheduled for transmit one by one if they had detected the rare event. In this case, node 0 is first scheduled and transmits the event packet which is received by the node 1 which remains in receive mode in all the time slots. The node 1 remains in receive mode and times out in the rest of the time slots. At the end in the additional time slot, the node 1 consolidates and sends the event packet to the CH node which listens to it. The CH node sends back the ACK packet which is then received by node 1. The CH node if it experiences the collision, listens again in the additional time slot in the inactive cycle.

C. Quick Loop Mode in iSDCP

The quick loop mode in iSDCP is also similar to the SDCP in which the node which had detected rare event for N cycles enters into quick loop mode with the CH node. This mode is to prevent excessive energy draining from the node that had detected the rare event.

The packet exchange diagram in Quick loop mode for iSDCP when node 1 is in quick loop is given in Fig. 9. In cycle 0, node 0 sends the SDP packet in TS0 while node 1 sends its event packet in TS1. Being an active cycle, the CH listens in the additional time slot also and times out having not received any other packet. During the cycle 1, the CH receives the event packet in TS0 and waits for any other additional packet in the additional time slot and then times out. TS0 is used by node1 as it is in Quick Loop mode else it is an inactive cycle.

During cycle 2, the regular cycle is processed with SDP packet from node 2 in TS0 and event packet from node 1 in Quick Loop mode in TS2. Similarly the quick loop mode is implemented for the other cycles.

It is to be noted that, the implementation of Quick loop is different for the active and inactive cycles. In the active cycles, the quick loop node does additional transmission to the CH and CH sends an ACK packet additionally. In the inactive cycles, the CH and the quick loop node exchanges event and ACK packet. Also, the CH node schedules its additional timeslot based on the schedule.

V. PERFORMANCE EVALUATION

The iSDCP is proposed to enhance the lifetime of cluster based WSN while maintaining the latency requirement of the network. The performance parameters like energy consumption, latency, scheduling, scalability, time synchronization and fault tolerance are analyzed for the proposed iSDCP.

A. Energy Consumption

The energy consumption of the cluster members and the cluster head for the proposed iSDCP is compared with that of LEACH and SDCP during the data collection in a single round consisting of N cycles.

The energy consumption of the sensor node is high during the packet transmission and reception. The radio transceiver is the highest power consuming unit in the sensor node. Hence in iSDCP, the packet exchange is reduced and the expected number of time slots for transmission and reception for both the cluster head and cluster member is given in the below table. It is seen that the iSDCP indicates reduced duration of radio activity and hence enhanced lifetime is expected from iSDCP than LEACH and SDCP protocols.

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

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Vol. 9, Issue 3, March 2020

TABLE I. TRANSMIT AND RECEIVE TIME SLOTS FOR N CYCLES WHEN NO RARE EVENT IS DETECTED

Type of Node	Protocol	Transmit Duration	Receive Duration
Cluster Head	LEACH	$N*N$	$N*N$
	SDCP	$2N$	$2N$
	iSDCP	$N+N/2$	$N+N/2$
Cluster Members	LEACH	N	N
	SDCP	1	1
	iSDCP	$\frac{1}{2}$ (on an average)	$\frac{1}{2}$ (on an average)

B. Rare Event Detection Delay

The rare event detection delay or latency is the time duration between the time, a rare event is detected and the time when it is detected at the CH. All the sensor nodes sense data during the start of each cycle and the latency is calculated for iSDCP. The rare event is communicated to the CH in max (1, N) TS. iSDCP protocol ensures that the data from the node detecting rare event is communicated to the CH node within the same cycle in which it is sensed. This property ensures that the latency in detecting the rare event is same as that of SDCP even though iSDCP involves active and inactive cycles during the data collection phase.

C. Scheduling

Scheduling the cluster member for transmission and cluster head for reception is similar to that for SDCP but demands additional scheduling for rare event mode and Quick Loop mode. Scheduling the receive time slot for CH is also relatively easier as it needs to be scheduled to a maximum of only for two time slots in a SDCP cycle.

For SDCP, the scheduling of nodes for transmission and reception is dependent on the values sensed. Only one node is scheduled to transmit in a time slot for SDCP and there is no chance for collision and there is no requirement for arbitration when there is no rare event. In case the rare event is detected by more than one node in the inactive cycle, then the CH sends the NACK packet and the rescheduling of nodes is done based on the NACK packet.

The scheduling complexity is compared with that for LEACH protocol. Over N cycles, a given CM node is scheduled to transmit at N cycles while for SDCP, it is reduced to 1. The scheduling complexity for LEACH is $O(N)$ while it is $O(1)$ for SDCP and iSDCP. It is to be noted that only one node participates in SDCP cycle in alternate cycles when there is no rare event.

D. Fault Tolerance

Any CM node failure does not affect the functionality of iSDCP and the WSN is also not partitioned as long as the CH is alive. Any failure of CM node causes timeout for the CH during reception and the iSDCP is continued without any modification.

E. iSDCP Applications

iSDCP for data collection and aggregation can be applied to any WSN with cluster, tree, star or mesh topology depending on application, provided that each of the nodes in the cluster can hear each other node. The iSDCP can be incorporated in the existing clustered architecture protocols wherever possible to extend the lifetime enhancement benefits. Further, if some nodes are identified as important, they can be configured to work in Quick Loop mode to provide additional monitoring facility by the CH node.

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

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Vol. 9, Issue 3, March 2020

VI. SIMULATION RESULTS

The ISDCP is implemented and simulated using ns2 simulator. The wireless sensor nodes are deployed in 100m*100m field distributed uniformly. The energy model is used for verifying the lifetime of the sensor nodes. One single cluster with 4 members and one CH node is used for simulation. To evaluate the energy efficiency of iSDCP, static clustering as reported in LEACH evaluation is used. The cluster head in static clustering collect data from CM nodes based on the fixed schedule throughout the lifetime and the energy consumption results are given in the table below.

TABLE II. SIMULATION RESULT

Initial Energy	Energy Consumption after 25 cycles			Energy Remaining after 25 cycles		
	LEACH	SDCP	iSDCP	LEACH	SDCP	iSDCP
1000mJ	9mJ	5mJ	2mJ	991mJ	995mJ	998mJ

VII. CONCLUSION

In this project work, iSDCP is proposed as an improvement to SDCP to increase the lifetime of cluster based WSN detecting rare events. This protocol is implemented with the additional requirement of maintaining the latency or the delay of detecting the rare event by the CH. To enable the rare event to be detected within the required delay, the rare event mode is incorporated in iSDCP which enables the data to be transmitted to the CH with change in transmit and receive schedules. In addition, a mode called Quick Loop mode is also incorporated to enhance the performance for continuously monitoring of rare events and also to provide priority treatment to important nodes in a network cluster.

The simulation results indicate reduction in hot spots and enhancement of lifetime of nodes with guaranteed delay. The improvement in energy savings is expected to be higher for clusters with higher density. The efficiency of iSDCP is expected to increase with increase in data packet size, increase in transmission power level, decrease in baseline node power. The size of the cluster is decreased in SDCP due to the fact that each of the nodes in the cluster must be able to receive the transmission of packets from every other node. The simulation results better lifetime than LEACH protocol and the Statistical Data Collection Protocol.

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Vol. 9, Issue 3, March 2020

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