Energy Efficient Event Driven Data Reporting System for Wireless Sensor Network

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***Abstract*-- Power conservation is important in sensor devices since battery life is usually one of the critical components in extending the life time of the sensor network. Cluster technology that enables a group of sensors working closely to form a single cluster head, has been a booming research field in sensor network. When cluster heads cooperate with each other to forward their data to the base station, the cluster heads closer to the base station are burdened with heavy relay traffic and tend to die early, leaving areas of the network uncovered and causing network partition. To address the problem, we propose an event driven packet processing and redundant data eradication using in-network data processing before communicating such data to cluster head or sink. The network nodes are assumed to generate periodic data packets that are reported to the destination via multi hop or single hop routing based on distance to the cluster head. The theoretical analysis and the simulation results reveal that our data reporting and routing schemes reduces the transmission loss and increase the network life time.**

Keywords: Event driven, clustering, Routing protocol, Data-reporting, Redundant data, Residual Energy.

1. INTRODUCTION

The hardware technology used in today's sensor devices may not be used in the future. There are several novel technologies that can be used for sensor device such as system-on-a-chip techniques, printed circuits and even science fiction-like technology such as Claytronics. Systems on a chip are electrical circuits that provide more than one function integrated as single chip. For sensors, systems on a chip that combine the radio transceiver, the microcontroller, high resolution ADC and a few sensing units on a single chip have a promising future. The adoption of high resolution ADCs simplifies the complete processing chain by pushing most of the processing in the digital domain. Integrating such a system on a chip with an antenna on a single board, the resulting hardware is easily added onto ordinary objects and products turning them into smart sensor device capable of handling multiple functions. Event-driven receivers can be used to reduce the power consumption of a main radio, while still guaranteeing short latencies [1]. Moreover, event-driven transceivers include full transceivers with minimal power consumption for applications as remote control, near-zero standby power, monitoring and active radio-frequency identification (RFID). The narrowband (NB) transceiver is optimized for biomedical applications, such as electrocardiography (ECG) and electroencephalography (EEG) sensor signals.

Unfortunately, neither time-driven nor query-based approaches work well for the applications with an event-driven data delivery model. In such kind of applications, data sources continuously collect the data but the data report to the data sink is triggered only if phenomenon of interest, referred to as an “event”, is detected. An event may happen anytime or not happen for a long time. Therefore, network and energy resources would be wasted if time-driven routing techniques were used to maintain routing trees or meshes continually and periodically. Also, query-based routing techniques are not appropriate because end-users do not know when and where events may happen. To the best of our knowledge, the routing design that effectively addresses the characteristics of the applications with an event-driven data delivery model is still an open problem of wide interest in WSNs[5].

The most recent proposals take into account the energy–efficiency, which is most important in the context of WSN. A first step to reduce the power budget of WSNs radios is through duty cycling: activating the radio at regular intervals and deactivating it in between. But this is still a sub-optimal schema; the radio will still be active when there are no data to receive or transmit. Adding a wake-up receiver such as this one allows keeping the main receiver inactive when no data traffic is present. As the nodes need to sleep most of the time, which increases the communication delay, which may not be suitable for the applications which has timeliness constraints. One such application is fire detection in forest, smart home/office and it's not delay tolerant. Sensor nodes are scattered throughout a forest to monitor temperature. Whenever they sense an abnormal raise in temperature, an alarm message is sent to the sink node, which is directly connected to the fire brigade. In this type of applications, the fire brigade needs to be warned within three minutes; otherwise the surveillance system is considered to have failed [4].

In most of the hardware components of a sensor node, the radio is usually the most power-consuming component. Compared to the power consumption of the microcontroller or the sensors, the radio transceiver often uses ten times as much power. These power-sink hardware components usually have various modes of operation including low-power modes which can be used to minimize power drain whenever the hardware components, or software services related to them, are not in use. This is because the CPU uses power for each CPU cycle executed and radio units use power for transmitting and receiving of each bit with network. The fewer CPU cycles needed to execute a piece of functionality, the less power the device uses. This applies to all types of software, from device drivers for hardware resources to user-level applications. Power optimization must occur both at the hardware and the software level. Without power-efficient hardware, it is difficult to achieve low-power operation. Similarly, without power-efficient software, it is impossible to achieve the low-power operation of the hardware [2]. The power consumption breakdown for the Tmote Sky board [3] of major components depicted in the Figure 1, the radio consumes as much power when listening for radio traffic as it does when sending data.

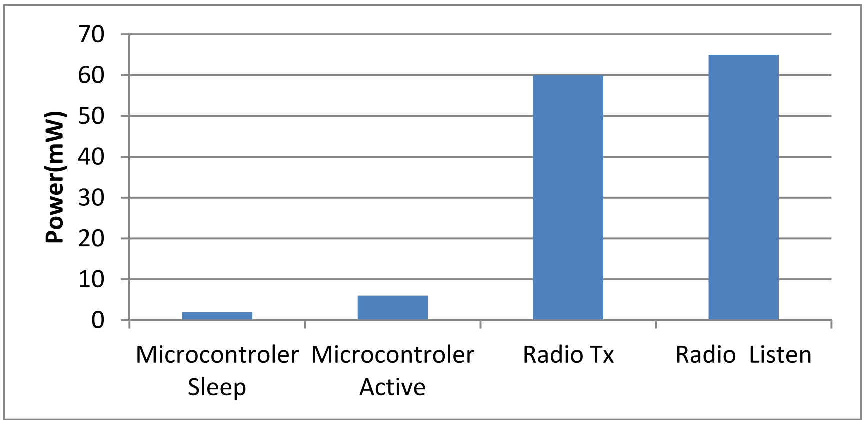


Figure 1. Energy consumption of sensor nodes

Most striking observation in the power consumption as shown is Figure 1, radio transmits and listen consumes more energy and the process of idle listening for radio traffic is very expensive. This is due to the processing required for modulating and demodulating the radio signal. For low-power radios, only a small portion of the power consumption is used to send the radio signal into the air.

2. RELATED WORK

Many data reporting algorithm have been proposed for wireless sensor networks in recent years, we review some of most relevant papers [12-16]. WSNs are deployed in human inaccessible area to collect relevant data and report to Base Station(BS) or sink after processing the data using in-network data processing. It can be classified as time driven, event driven and user query based on the data reporting. In time driven, when sensor nodes periodically sense the environment, process the sensed data using in-network data processing and transmit the data of interest continuously over time, or as event-driven, when sensor nodes react immediately to sudden and drastic changes in the value of a sensed attribute due to the occurrence of a certain event [8]. In query based system user can send sql like query to get the interested data from the particular sensor node or sink. The literature [9], has proposed a data collection strategy by using network coding for efficient data collection in event driven WSNs, which guarantee the successful decoding for all the encoded packets.

In some approaches not only the sensor nodes are detecting an event of interest but also those nodes will potentially detect the event in the near future become engaged in the time-driven data-reporting process. In such applications a hybrid data-gathering protocol [10] that dynamically switches between the event-driven data-reporting and time-driven data-reporting schemes. Tiered or hierarchical architecture with robot have been used in largely deployed WSNs in order to perform load balance operations and enable wireless sensor system to scale up [11]. In tiered WSNs, the network is divided into manageable clusters or zones and each cluster will have cluster head or a higher performance node is placed to store the data sensed by nodes. In addition, each cluster will be assigned one or multiple robots aiding in data collection tasks. The deployed static sensor nodes monitor multiple kinds of events such as location specific environmental events that occur at random locations, or trajectory tracking events. Once an event is sensed and high fidelity data about the event is stored, a small control packet that describes the location of the event is sent (multi-hopped) to the BS. The BS then keeps a record of all the nodes and that holds the data to be collected and communicate the same to robot before its starts the tour to collect the data. This approach will avoid power deplete of the sensor nodes around the BS due to more traffic when all the nodes start sending the data to BS or Cluster Head (CH). As the nodes need to wait for the robots to transfer their sensed data, which increases the communication delay.

TEEN is an event-driven routing protocol, where each node will decide whether to report data or not based on the threshold values [17]. If the sensed value and a change in value are beyond the threshold, the node must switch on its transmitter and report it. Event-based Energy Efficient Routing Protocol has been proposed in [16] and used the tier based architecture for data dissemination among the sensor nodes where we can prolong the network lifetime. Energy efficient continuous and event-driven monitoring for WSN in [12] has proposed the deterministic energy efficient protocol for sensing and its performance has been compared with the LEACH protocol. LEACH protocol is applicable to the model of continuous data streaming with the precondition that all the nodes are active and involved in data collecting and transmitting. The Scalable Protocol for RObust Information Dissemination (SPROID) algorithm [13] has been used to achieve the reliable data delivery in event-driven WSN. In this algorithm data generated synchronously or otherwise, sequence numbers can be used within the unique identifiers to determine the freshness of data and super-cede older data. In [14], multi-hop algorithm has used to forward the data collected in event-driven wireless sensor network to sink, all nodes are in sleep state and conduct periodic listening when no events occur. Authors of [15] have proposed the pattern recognition system on each involved node that is able to extract characteristic features of the upcoming data stream during an event detection. The features are distributed to the local neighbourhood via broadcast and fused to a combined feature vector. To evaluate the fused feature vector, Euclidean-distance-based Nearest Prototype Classifier has been used and the unknown event can be mapped to one of the trained prototype vectors, it has recognized; if not, it is ignored. This method proposed to achieve the secured data from the sensors.

3. SYSTEM MODEL

In this paper we propose an energy efficient event-driven data collection scheme in a cluster based wireless sensor network. Event detection and data collection means to recognize environment events with the help of randomly deployed and cooperatively working group of sensor nodes. As shown in the Figure 2, sensing unit generates an interrupt when data is received (event) that is picked by a device driver. Device driver needs to make an additional effort to discover details about the type of event that has occurred, if the sensor is capable of detecting the multiple objects. The communication stack is informed by the device driver that some data has been received. The communication stack identifies if there is new data to transmit then it dispatches the event. The subscribed neighbour sensor nodes receive the events. At the same time application layers also receives the same dispatched event as it already registered the events of communication stack. Application layer receive an event and process the data and inform the applications about the new data.

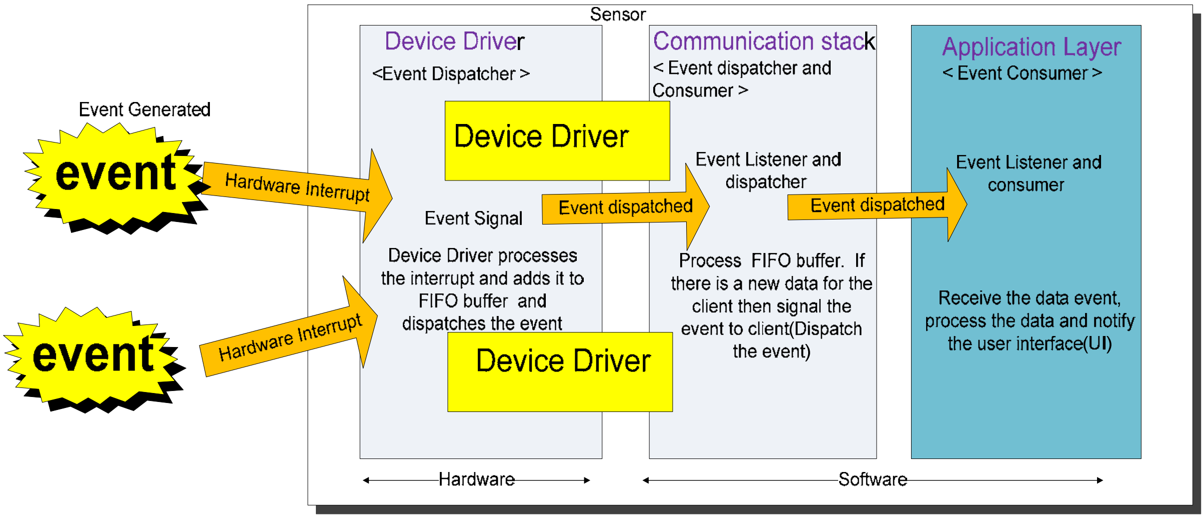


Figure 2: System architecture of event driven WSN

We focused on clustering and routing algorithms and the following are the assumptions of wireless sensor network.

1. Sensor nodes are organized into clusters and it has cluster head(CH) and cluster member(CM).
2. Clustering is performed after every predefined intervals (T_{Intvl}) to distribute the load on overall network.
3. The communication range of the sensors is fixed. Each node has a unique ID for its identification and knows its location information via GPS or through some positioning methods.
4. It is assumed that all sensors are randomly and densely deployed all over the monitoring region such that no isolated node exists in the network.

A. Problem statement

The previously proposed traditional algorithms are having certain drawbacks such as each source node detects an event and transmit its detected data packets to neighbouring nodes or CH for aggregating the data detected by the multiple sensors. This leads to lots of redundant data communication and creates network congestion as each detector node participates in sending the same data to the CH. There are two problems associated in event driven sensor network, one is to detect the same data by multiple sensor nodes and communicate the redundant data to the base station or sink node. Energy efficient data reporting is one of the most important functionality in the sensor network [6]. Data reporting means transmission of data generated by node over whole network to sink. In a network operation much energy of nodes is wasted in idle listening [7] which is equal to the power consumption of transmitting the data.

With the advanced embedded technology, newly designed wireless sensor node can operate on both ultra low power (event driven) and normal radios such as Zigbee or WiMedia. Use of these two radios in a wirelesses sensor network prolong the network lifetime with provision of turn off the main radio when an event data is not there to communicate. Ultra low power radios operate in very low bit rate, ideally below few mbps. There are different types of ultra low power radios that have been used in multi-region like industrial, scientific and medical applications. Event-driven receivers are ultra low power devices and they can be used to reduce the power consumption of a main radio, while still guaranteeing short latencies.

B. Challenges of data reporting

The many published methods assume event-driven sensing; where sensors are collecting the data only when events are generated around the sensors and reporting to the mobile sink whenever it comes closer to the detected sensor nodes. In most of the proposed methods mobile sinks starts from the base station after downloading the collected event data from the sensors and visits sensor nodes in linear order, in such cases sensors which are already collected the data has to wait until mobile sinks comes closer. This leads to stale data communication to base station. In an event driven WSN, multiple sensors may sense the same event when the event triggers with their sensing range and if the mobile sink collect the data from all detected sensors or all detected sensors may start sending the data directly to base station or cluster head. Another crucial matter is that all sensors in the same WSN must share limited bandwidth which often leads to congestion and packet drop[18]. The simultaneously sending the same event data from multiple sensors to sink will leads to network congestion, energy depletion of multiple sensors and data redundancy in sink.

4. Proposed Approaches

A. *Selection of Detector node for data reporting*

- When an event occurs, surrounding sensor sense the event data
- Store the event data along with time stamp on local cache memory of the sensor
- Each detector nodes broadcast their residual energy and location info among the detector nodes
- Detector nodes start the in-network data processing to elect the node to transfer the data to sink node based on the residual energy and distance to the base station.
- Each sensor have limited processing unit and small amount of memory available which should be utilized to temporarily store till the completion of in-network data processing to elect the detector node. Sending the sensed data soon after sensing may lead to network congestion along with redundant data as all detector nodes participate in sending.
- In Figure 3, a particular cluster region is consisting of a CH, CNs(CN1, CN2, CN3…) which are at a distance(d1,d2,d3… respectively) from CH. An Event occurs within the sensing range of CN1, CN2, CN3 and that event has been detected by all the three CNs. If every CN sends that detected event to CH, then this results in data redundancy and energy depletion. Now in our proposed approach the CNs does an in-network data processing where they find out which CN is having more residual energy and which is at shortest path to CH to communicate the event. Thus the communicator is selected to communicate the event to CH avoiding data redundancy and energy depletion. The in-network data processing (using shortest path algorithm) and pictorial representation are shown in Figure 4.

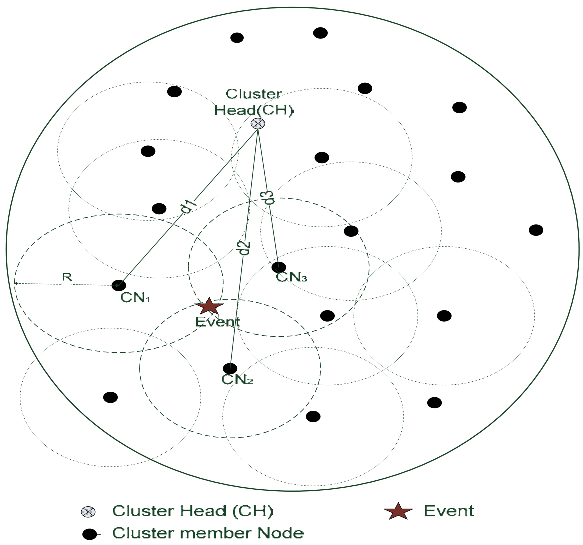


Figure 3: Event triggered within cluster area

We used the energy model as in [20]. In this model energy consumption for transmitting K_{data} bit is equal to

$$E_{Tx}(K_{data}, d) = K_{data}(E_{dpb} + \xi fs * d^2) \quad \text{-------} \ 1$$

And energy for receiving the K_{data} bit is equal to

$$E_{Rx}(K_{data}) = K_{data} * E_{dpb} \quad \text{-------} \ 2$$

Where ξfs is constant and $\xi fs = 100$ pJ/bit/m^2 and $E_{dpb} = 50$nJ/bit

- Estimate the energy required to transmit the event data to the CH from the detector nodes using the energy model equation 1. The sink node is assumed to know all sensor nodes in fixed location that are having a limited energy. Sensor network divided into multiple cluster regions where each cluster region has a number of cluster nodes (CN) and a cluster head and each cluster head is assumed to know all the nodes location.

To find the energy to transmit the data from each detector node to CH as below,

For i = 1; i < N; i++

$E_{Tx}[i](K_{data}, di) = K_{data}(E_{dpb} + \xi fs * di^2)$

$E_{ra}[i] = E_r CN[i] - E_{Tx}[i]$

Where E_{Tx} is energy dissipated per bit to transmit.

$K_{data} =$ K number of bits per packet transmission.

$E_{dpb} =$ Energy dissipated per bit

di = Distance between sender and receiver

ξfs = A constant for amplifier energy consumption

$E_{max} = E_{ra}[1]$

J=1;

For i = 1; i < N; i++

If($E_{max} < E_{ra}[i+1]$)

$E_{max} = E_{ra}[i+1]$

J = i+1;

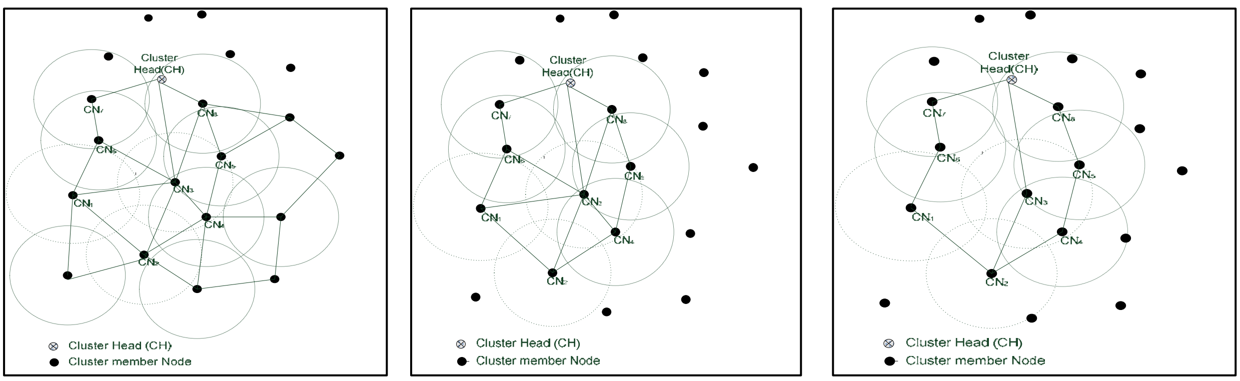
E_{ra} is residual energy after transmitting the data , so find out the node which will have the maximum residual energy after transmitting the event data to CH. Each detector node performs the in-network data processing and finds out the E_{max} (maximum residual energy of j^{th} detector node). If processing node finds that the residual energy of a node is higher than other detector nodes then that node has to start sending the data to BS.

B. Energy efficient Routing

1. Elected node checks the positive position (distance from each neighbouring node to CH) and residual energy of neighbouring node.
   Positive position nodes should comply with the following rule
   $d(CN_{elect}, CH) >= d(CN_{next}, CH)$ ---------- 3
2. Compute the possible shortest path from the elected node to CH using equation 3 , as shown in the Figure 5(a) and (b)
3. Select the first and second shortest path and compute the total residual energy of each path.
   Residual energy of shortest path is sum of elected node, cluster head node and remaining nodes in multiple hops.
4. Compute the total energy required to transmit the K_{data} from elected node to CH using equation 1 for first and second shortest paths as shown in the Figure 5(c) .
   Total remaining energy after transmitting the K_{data} using first shortest path $E_{fs} = E_{trfs} – E_{rfs}$

E_{trfs} is total residual energy of first shortest path, E_{rfs} total residual energy required to transmit the K_{data} using first shortest path. Total energy remains after transmitting the K_{data} using second shortest path $E_{ss} = E_{trss} - E_{rss}$
if $E_{fs} \geq E_{ss}$ then use the first shortest path for transmit the data otherwise use the second shortest path for transmit the data

In proposed routing algorithm there will be some computational overhead for each sensor node (to decide the communicator among themselves to the CH) which will take a negligible energy. The shortest path calculation happens only once after forming the CH and the same path will be used for subsequent event data communication.



(a). All possible paths (b). All positive paths (c). best shortest paths

Figure 4: Shortest path detection algorithm

5. Simulation Results

The proposed approach is simulated and evaluated using Castalia[19]. Castalia is simulation software selected to implement the new models. Castalia is an open-source simulator for WSN and Body Area Networks (BAN) and it's based on modular, component-based OMNet++ platform. Castalia simulator has fundamental features such as advanced channel model and advanced radio model based on real low-power radios, extended provisions for modelling sensing and the physical process, clock-drift model and power consumption model.

We assumed N number of sensor nodes in the WSN and they are uniformly distributed in the network coverage area. Each node has a binary event detector with sensing range r. It is assumed that network covers 50 nodes of equal energy are uniformly distributed on 100m x 100m area. The cluster head is formed by the sink and source node randomly sends data packets of size 64 bytes. As shown in the Figure 5, the total residual energy of the nodes decreases in small stages. But comparing to LEACH, an Energy efficient clustering approach, the proposed approach makes sure that more residual energy persists with sensor nodes.

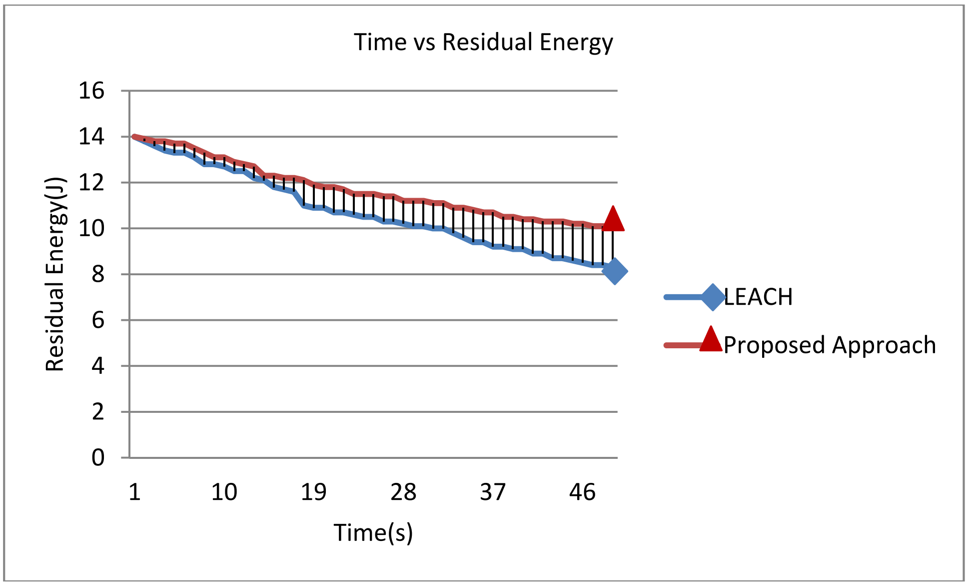


Figure 5: Residual energy after number of passes

6. Conclusions

This paper discusses the existing continuous and event driven data collection and reporting protocols for wireless sensor network. The majority of the existing methods have concentrated on achieving the energy efficiency by using routing protocols but most of them have not concentrated on the data redundancy before communicating to the base stations or neighbour nodes. The redundant data communication energy constrained wireless sensor networks would lead to a lots of energy depletion. Most routing protocols with continuous data reporting cannot support the critical events, e.g. forest fire detection, intruder detection. Proposed energy efficient event driven data reporting and routing protocols reduces energy depletion, reduces data redundancy at the same time increases the energy efficiency using in-network data processing.

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