Reducing Packets Delay in Event-Driven Applications of Wireless Sensor Networks

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Abstract

Event-driven WSNs applications are delay-critical applications where packets may considered useless when delivered lately. On the other hand, neighbor nodes tend to have intersected covered area, so they may sense the same information at the same time. Forwarding the duplicated information through the network has two main disadvantages, first, it uses network limited resources inefficiently, and second is the arising of packets delay because the neighbors packets obstacle each other. In this work, an algorithm is suggested to reduce the number of transmission required to inform the BS station about an event by exploiting the intersected area of coverage between neighbor nodes. In the simulation, THVR routing protocol is used for forwarding packets through the network with and without the suggested algorithm. The results show that the packets average delay is effectively reduced.

Introduction

In recent decades, sensing applications increased drastically as a result of advanced technologies such as Micro-Electro-Mechanical Systems (MEMS), Very Large Scale Integration (VLSI) and wireless communication which mainly contribute to the providing of small size and low cost sensors with an integrated sensing, processing, communication, and power units [1]. These devices usually called motes, Sensor Nodes (SNs), or nodes.

In general, Wireless Sensor Networks (WSNs) consist of a large number of SNs distributed to cover an interested area to monitor and detect specific phenomena or signals. Such networks are characterized by many powerful features that make them suitable for many applications. Some of these features are low cost of sensing nodes, ease of installation compared to wired network, the ability of nodes to configure themselves, and the compensation of node failure automatically. WSNs are exploited in many fields such as environment monitoring, health care, agriculture, and military [2].

Sensors are devices used to detect real world phenomena which can be integrated in different devices or operated independently. Sensing circuitry monitors the surrounding environment or interested object and measures its condition then transfer this information into electrical signal [3].

In order to cover the intersected field, a large number of nodes may need to be distributed through it. Because usually no other devices exist in the field, SNs not only responsible for sensing and sending their information but also forwarding other nodes information until reach to the BS.

WSNs applications have specific performance and quality requirements that need to be met during the operation of the network. In general, most WSNs applications demand low latency, and high reliable service from WSNs. On the other hand, WSNs have unique characteristics such as limited bandwidth, storage capacity, processing capability, and energy capacity. The most extremely constraint in WSNs is the energy because SNs depend on batteries and when these batteries depleted they will become useless and the replacement of these batteries may be difficult or even impossible. So the problem is how to provide an application with minimum delay and reliable services with an optimum use of system resource especially the node energy.

WSNs have specific features that make them preferable for a lot of applications such as the ability to operate in harsh or inaccessible environments and also providing accurate details about the interested field [4, 5].

The density of the distributed nodes needs to be high enough to increase the ability of WSNs to provide accurate details. However, high node density usually lead to data redundancy arising. data redundancy has some advantage and disadvantage[6]. The advantage is that data redundancy can be exploited to increase the reliability of data delivery; while the disadvantages are exhausting the network limited resources, increasing the demand on the dedicated channel and hence increasing packets congestion which finally lead to raise the average delay of the received packets [5].

There are three types of data redundancy:

-temporal redundancy

-spatial redundancy

-and information redundancy

Spatial redundancy means colleting the same information by more than one node and sending them to the BS which occur as a result of providing more than necessary system resources [7]. The degree of redundancy can be measured depending on the nodes density. Sending the same information more than once forming what is known as temporal redundancy. At last, information redundancy is common in all networks when appending some bits to the original information which can be used for error detection and correction.

Intermediate nodes may aggregate the packets received from these nodes to reduce the number of transmissions. *Data aggregation* is defined as [8, 9] the operation of combining of data received from different sources by using max, min, average, and suppression functions. Although data aggregation requires a lot of data processing, it reduces the number of transmissions and processing consumes less energy [10]. Data aggregation technique is used for traffic optimization and energy reservation in a number of routing protocols [11, 12, 13].

Data Delivery Model

WSNs applications can be differentiated according to the data delivery model they use for the delivery of the information to the sink. The data delivery can be *time-driven*, *query-driven*, or *event-driven* [14]. In time-driven (continuous) model, a SN continuously sends its data at specific rate, while the data sends from a node only when it receives a query form the sink in query-driven model. In event-driven model, a node will send its information to the sink when it detect event. Some applications use a hybrid model, in which, a combination of two or the entire three models is used for information delivery. The data delivery model has a great impact on choosing the appropriate routing protocol taking into consideration, routing stability and energy consumption. For instance, a hierarchical routing protocol is the most efficient for time-driven data delivery applications. This is due to the fact that a high probability of data redundancy generated in such applications can be aggregated during the forwarding to the sink. As a result, energy is saved and the traffic on the network is reduced [15].

The suggested algorithm applies to event-driven WSNs applications so in the following, the requirements for each data delivery model are presented [14]:

1. ***Event-driven data delivery***: in event driven, a SN has no specific time to send its data and sends a data when an event is detected. Applications with such data delivery model require a little or no delay, with high reliable data transmission. Also, it is not end-to-end application, where one end is the sink and the other end is the event detecting nodes. When an event is detected, a data redundancy is expected. The traffic may be suddenly burst at the region where the event is occurred, so multiple routes must be always available to avoid traffic congestion and delay.
2. ***Query-driven delivery model****:* unlike event-driven delivery model, a node in query-driven model sends its data only when it receives a query

from the sink node. The application specifies delay toleration in this model. In general, the applications require the data received quickly and reliable.

3. ***Time-driven delivery model (continuous):*** the data is continuously sent from source nodes to the sink as in real-time applications or each node is only sent at specific time as in non-real time applications. Real-time applications delay is intolerant and also require high reliability, while delay and packet loss are tolerated in non-real time applications.

Related Works

In this section, some of the previous works including routing protocol that provides techniques to reduce packets delay and algorithms try to alleviate data redundancy to provide an overview about the directions of the research in this field.

Manjeshwar and Agrawal in 2001 [16] propose TEEN; a hierarchical protocol that applies data-centric mechanism, designed to make a network response quickly to sudden change in the reading of sensor nodes. In this work, threshold is used to enable nodes to send their data packets. APTEEN [17] is a modified version from [16] where the periodic transmission issue is covered, where hard-threshold, soft-threshold is proposed for periodic data.

T. He et al. in 2003 [18] propose a protocol that provides soft real-time guarantees services. In this protocol, the position of neighbors nodes is used to select the next forwarding node, and that effectively reduce packets delay. FT SPEED [19]: A Fault-Tolerant, Real-Time Routing Protocol to overcome the void region (the situation of finding no neighbor node closer to the sink) by defining void area nodes and void edge nodes. Yanjun Li et al**.** in 2009 [20] develop a routing protocol (THVR**)** in which nodes in the network use the information of two hops neighbors to select the appropriate path for forwarding a packet to its destination.

In Tiny AGgregation (TAG) proposed in [21] a tree is expanded to cover the whole network, then the up-level nodes is responsible for aggregating the down-level nodes data. Manjhi et al propose Tributaries and deltas aggregation algorithm [22] where multi-paths are provided through the spanning tree and the region of aggregation changed according to the network state. In energy-efficient unequal clustering scheme (EEUC) [23] the whole network is divided into clusters and the head of each cluster which is selected locally been responsible for data aggregation. The adaptive sampling algorithm (ASA) [24] reduces the sample frequency of the transmitted packets that can provide adequate information of the sensed information to the BS. Adaptive spanning tree (AST) algorithm [25] is proposed that apply alternative father nodes and random waiting time to form adjusting spanning tree.

The suggested algorithm

In WSNs, it is normally that neighbor nodes detect the same event at a specific time then inform the BS about this event by sending packets at the same time approximately. Because of the synchronized detection of an event, the contention for access the channel increases drastically, so an extra waiting time will be imposed on the nodes to obtain the busy channel which in turn increase the packets delivery delay. Also the congestion will increase the probability of data collision. On the other hand, this congestion also may leads to postpone the specification of the event zone, for example when the nodes A, B, C, D, E, F, G, and H detect an event as shown in Figure 1, if the nodes A, B, C, and D accessed the channel and sent their packets to the BS respectively, the entire event zone is not perfectly specified. On contrary, if the nodes A, C, E, and G win the competition and access the channel, then the determination of the event zone is more thoroughly.

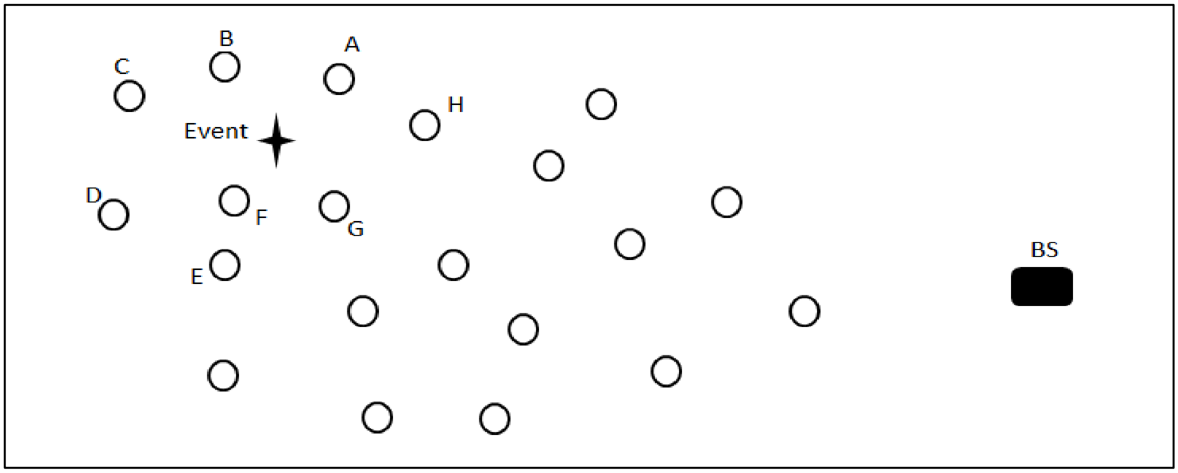

Figure 1 Group of nodes detect an event

In the suggested algorithm, the neighborhood of SNs is invested to decrease the number of transmission required to inform the BS about an event. At first, each node in the network negotiates with the closest neighbor to become its partner. For example, when an event is detected as shown in Figure 3.21, at first, the nodes divided into two groups, nodes and their partner belong to different groups (in Figure 2, first group nodes indicated by black color and letters without dash, and second group nodes indicated by white color and letters with dash). When an event detected at specific zone, the waiting interval for channel access is different for the two groups, so to access the channel, the first group nodes need to wait less than the second group nodes. This will ensure that the first group nodes send their packets first. When sending their packets, a node in the first group tells the BS that it and its partner detect an event. And hence when this partner knows that its partner send its information to the BS, it stop waiting to access the channel to sending its information about the event. The differentiating of waiting interval leads to decrease the probability of data collision and the second group nodes also listen to the packets sent by the first group nodes and once they find the sender is their partners, they give-up the transmission and hence the required transmission packets will decrease effectively.

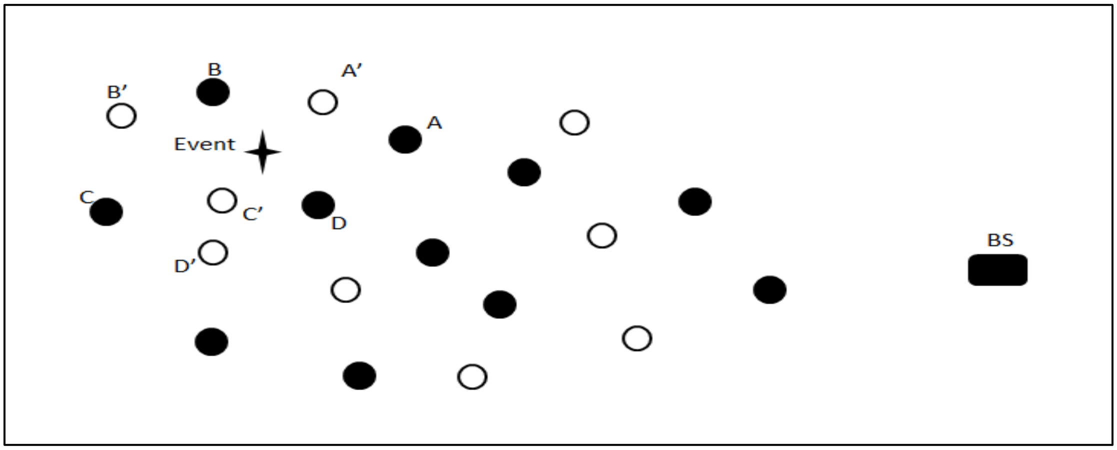

Figure 2 Nodes status in the suggested algorithm during event detection

Simulation Result

Two different networks are used to test the suggested algorithm as shown in Table 1. For the test of algorithm, THVR routing protocol is used to forward packets to the BS with and without the suggested algorithm and measure the average delay of 10 events in the two different cases. Network-1 and Network-2 deployment is shown in Figure 3.

Table 1 Networks characteristics

	No of Nodes	Field length	Field Width	BS position	Node Transmission Range m^2	Packet Length Kb	Bandwidth Kbps
Network-1	100	100	100	Side	40	4	250
Network-2	150	100	100	Side	40	4	250

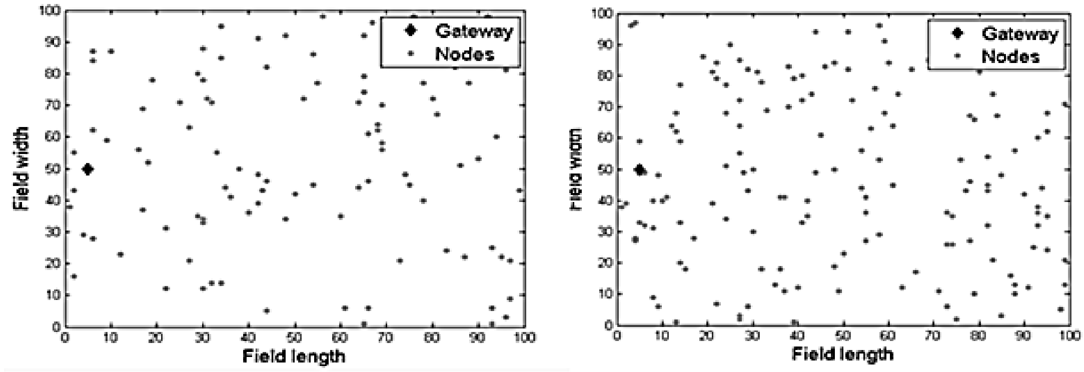

Figure 3 Nodes Deployment in Network-1 (left) and Network-2 (right)

For Network-1, most of the nodes get partner as shown in Table 2. In the table, the Symbol '-' means the node has no partner.

Table 2 nodes and their partners in Network-1

N-id	P-id	N-id	P-id	N-id	P-id	N-id	P-id
1	79	23	63	85	-	57	82
3	74	25	29	2	12	58	75
4	77	26	94	5	65	69	89
9	35	32	66	7	11	80	96
10	33	36	40	8	68	81	84
15	59	38	55	17	49	13	93
16	47	39	67	18	22	14	19
27	60	46	92	20	72	21	41
31	78	48	98	30	62	24	90
37	42	70	95	34	56	54	99
43	73	61	-	44	64	88	100
50	97	86	-	51	76	91	-
53	87	6	45	52	71	28	83

the average delay for two cases, at firstly, by forwarding the packets using THVR routing protocol without using the suggested algorithm, and secondly, after applying the suggested algorithm as shown in Figure 4.

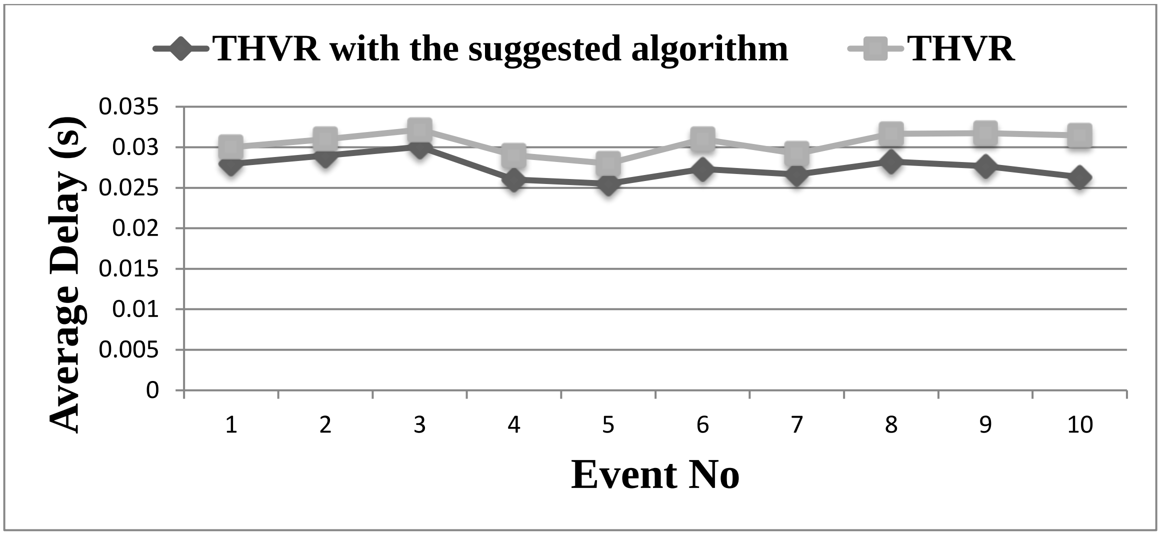

Figure 4 Average delay of 10 events in Network-1

Where the average delay when applying the suggested algorithm decrease to approximately 90% of the average delay without using the algorithm, so approximately 10% of the average delay is decreased.

In Network-2, the partnership between nodes is shown in Table 3. Also the symbol '-' means the node has no partner.

Table 3 nodes and their partners in Network-2

N-id	P-id	N-id	P-id	N-id	P-id	N-id	P-id
1	85	28	111	65	136	21	88
2	122	29	84	66	70	22	94
3	137	30	31	67	140	24	105
4	116	33	115	69	109	25	107
5	103	34	120	71	150	26	147
6	117	35	98	72	87	27	32
7	125	36	121	73	82	51	55

8	**119**	**37**	**62**	**75**	**86**	**52**	**76**
9	**80**	**38**	**130**	**77**	**-**	**53**	**126**
10	**60**	**39**	**74**	**79**	**139**	**57**	**78**
11	**132**	**40**	**108**	**83**	**102**	**58**	**144**
12	**104**	**41**	**112**	**89**	**134**	**63**	**149**
13	**44**	**42**	**64**	**91**	**123**	**127**	**138**
14	**54**	**43**	**128**	**92**	**124**	**131**	**148**
15	**59**	**45**	**114**	**93**	**97**	**135**	**141**
16	**23**	**46**	**133**	**95**	**96**	**143**	**-**
17	**81**	**47**	**61**	**99**	**129**	**146**	**-**
18	**56**	**48**	**118**	**101**	**145**	**113**	**142**
19	**68**	**49**	**-**	**106**	**110**	**50**	**100**
20	**90**						

In Network-2, the average delay decrease to approximately 68% when applying the suggested algorithm. Hence, approximately reducing of 32% of the average delay is achieved. Figure 5 shows the average delay of the 10 events in both cases (with and without the suggested algorithm). It is obvious that in Network-2 more reduction in delay is achieved and that because of the higher node density compared to Network-1.

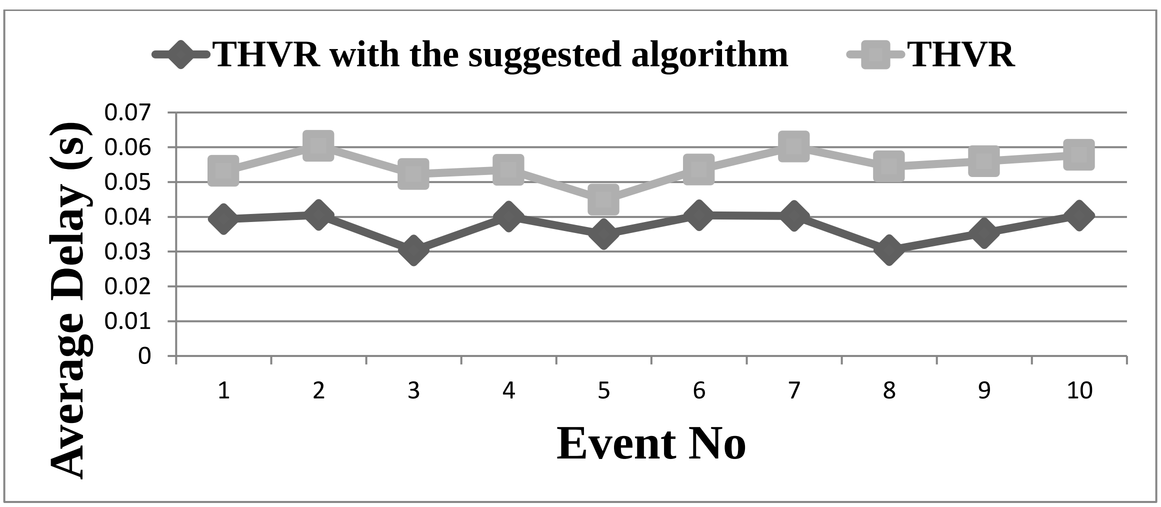

Figure 5 Average delay of 10 events in Network-2

Conclusion and Future suggestion

By using the suggested algorithm and exploiting the tendency of data redundancy in WSNs, packets delay can be effectively reduced and this is because less packets transmitted through the network alleviates the demand on the dedicated bandwidth and reduce the packets congestion and that leads to reducing the waiting time of queued packets, so in consequence, packets delay can be reduced.

In the future, the partnership between neighbors can be extended to include more than two nodes. Also, the nodes may be allowed to make partnership with more than one node independently according to the intersection coverage area.

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