A review of data collection approaches in linear wireless sensor networks (LWSNs)

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Abstract. Using wireless sensor nodes in monitoring systems have attracted significant attention over the past few years. Wireless sensor networks (WSNs) are key technology that extensively applied in many fields, such as transportation, health-care and environment monitoring. Different applications of WSN require different structure of nodes deployment form. For example, pipelines, border and Highway monitoring system, these applications have produced a special class of WSN in which nodes deployed in linear structure to form a linear wireless sensor network (LWSN) that extended to long distance area. In this paper, Applications and classification of LWSN are presented. Also, related works of data collection approaches in LWSN are provided, which classified into two categories named multi-hop data collection approach and mobile data collection approach (MDC). In addition, cons and pros in the existing approaches and future trends are also discussed.

1. Introduction
In recent years, evolution and advance in micro electro-mechanical systems (MEMS) has enabled the development of low cost, low-power and small size micro sensors [1]. A wireless sensor network can be described as a composition of tiny sensor nodes that communicate wirelessly with each other to sense some specific actions in an interested field. Each sensor node consists of main components[2]: processing capability, memory, RF transceiver, power source and in some cases equipped with GPS. WSNs have deployed in different fields in order to provide online insights into the conditions, demands and performance of the observed infrastructure. WSN can be deployed in different structure of network topology according to applications used in. In some critical applications, WSN can form a linear or semi linear network topology which is called Linear Wireless sensor network (LWSN). Linear Wireless sensor Networks (LWSN) is one of special classes of network topology for wireless sensor networks [3]. In addition, LWSNs have unique features such as long distance and narrow network compared to other network topology. LWSNs have been used in different monitoring applications such as border, river, railway, power line cable, road conditions and etc[4]which will be explained in details in next sections. In LWSN, sensor nodes are distributed in linear structure with
narrow region along the network with distance reaches to hundreds of kilometres [5]. Therefore, it’s not possible to communicate with the sink in single hop form. Moreover, traffic generated by far sensors from the sink will have to use other nodes to transfer their generated traffic. Therefore data traffic will be delivered within significant delay[6]. Proposed schemes for balancing energy in WSNS are not suitable for LWSN as nodes in LWSN have unique characteristic [6]. Nodes near the sink deplete their energy quickly as they deal with heavy traffic compared with other nodes in the network[3]. Load balancing between sensor nodes in LWSN is challenge For example network structure of LWSN is not like mesh topology as only few nodes can communicate with sink node. Due to restricted constraints WSNs such as energy, memory capacity and processor in general, it is very important to reduce energy consumption and provide reliable data collection in LWSN. Therefore different works have been proposed to optimize the data collection in LWSN by using different techniques. However, there are many challenges and issues need to be taken into consideration while developing data collection scheme for LWSN. Therefore, this paper is presented to give an insight of LWNS. In addition, different approaches that aimed to provide energy efficient and reliable data collection in LWSN are surveyed. Moreover, we find out that the related works can be categorized into two categories named multi-hop approach and mobile data collection (MDC) approach, each approach used in data collocation in LWSN has its own cons and pros which are also discussed. Finally, some future trends also provided in order to improve the existing schemes.

2. Classification of LWSN

In this section presents a classifications LWSN which can be classified into different categories according to topological point of view as follows [5]

I. Thin LWSN: it describes a LWSN structure when nodes are lined up in one dimensional geographic area. Also, Sensor nodes can be distributed as straight line or curved line depending of network topology.

II. Thick LWSN: it means that sensor nodes are distributed into two or three dimensional geographic area.

III. Very thick: Sensor nodes are distributed randomly and lined up in between two lines.

3. Applications of LWSN

Some of the applications of WSN where nodes deployed in linear structure include.

3.1. Highway Road Monitoring

Using WSN for Highway Road monitoring with less human efforts is very important in our daily life. Many sensors are lined up along a road for detecting traffic jam, crossing the limited speed, and the continued monitoring of the road. A WSN can work during different weather condition such as fog or presence of dust, rain and even at night[7]. Using sensor nodes in road monitoring can lead to collect real information on road situation which is very necessary. By analyzing the collected information, traffic jam and car accidents can be avoided and reduced [8-9]. Another use of road monitoring is that to give an alarm to driver when he/she crosses the speed limit or any accident happened along the road [6].

3.2. Monitoring of AC power lines

Collecting and monitoring the environmental information of the long-distance transmission electrical lines by the WSN technique is one of the important application. In monitoring system of power line, information which is collected by sensor node would be valuable for the utility company to diagnosis the problems that can happen caused by a certain failure in the equipment or overusing and loading of AC power lines. By monitoring a power line conditions, such as voltage, temperature, humidity, and others conditions, provider companies can able to anticipate any equipment failures and unexpected problems. This result in creating a better maintenance
schedules and improving company productivity and early predication of any equipment failure, therefore maintenance cost is reduced [6][10].

3.3. Border Monitoring

Border monitoring [11]-[12] is one of the main concerns of every country in order to ensure of security and protection from any illegal entrance or intruders. The long border has made a border monitoring very difficult matter and costly. Therefore, the advancement of technology has released WSN which can play an important role in such application. WSN monitoring system in border surveillance, applications, focuses on collecting information by using different types of sensors, such as seismic, camera, thermal camera, and motion detectors. Thus, sensor nodes can form a line control and notify if any intruders cross the predefined specific area. Finally, sensor nodes process this information and send to the central station which is responsible to take an appropriate defense action.

3.4. Oil and gas Pipeline Monitoring

In most petroleum producer countries there are wide network of pipelines carrying oil and gas. These networks involve many parts from pumps, control station, pipelines and other equipment. As oil and gas have key role in world’s economy, managing and controlling the transportation mainly depends upon huge pipeline. Pipeline infrastructures need to be monitored frequently to know the pressure of the oil and gas, temperature, the flow rate, quantity flown and other necessary measurements. The knowledge of these measurements is very essential to avoid failures or to know places of failures and other such as leakages. The place of measurement should be along the pipelines and involve remote area that cannot protect or monitored always. Thus the best solution to such problem is the use wireless sensor network along the pipelines transportation.

3.5. Railroad/subway monitoring

Railroad and subway [6] are one of most important infrastructures of each county which serves to support the transportation service. Security and safety of this infrastructure is the most concern in many countries. Therefore, many researchers have investigated the use of WSN in railway and subway infrastructure to monitor the health condition. For example, sensors can monitor dynamic strain caused by the passing trains as well as provide early detection of critical and dangerous cracks.

3.6. Some of Structural Health Monitoring

Another area of interest where sensor nodes can be used in Structural Health of tunnel[13], road [8] and bridge [14] in order to provides a costly and timely inspection compared to the typical structural safety assessment which depends on manual and visual inspection. Moreover, damage can’t be seen when it located inside the structural elements, thus using sensor nodes in SHM systems is very important to check the structural integrity and condition in an automatic, efficient manner and remotely.

3.7. River Monitoring

In recent years, environmental monitoring has become one of important concerns. To provide a real time, efficient, and economic monitoring, hence WSN has been used to for a river application monitoring to provide some important measurements regarding to river application, instead of using the traditional way of measurements which can be time consuming and costly. For example, sensor node can measure the level of the water and river pollution to avoid any further risks and potential hazards of natural disasters[15][16].

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4. Related works

For data collection in LWSN, there are different approaches have been done by number of researchers to tackle the obstacles in data collection for this type of network structure. These approaches can be categorized into multi-hop and mobile data collection approaches. For data collection in LWSN based Multi hop approach, authors in [17] proposed a hierarchical network architecture where three types of nodes are introduced and defined with different functionalities named basic sensor nodes (BANs), data relay nodes (DRNs) and data dissemination nodes (DDNs). Each kind of nodes perform different task according to its function. BANs are the basic node which is responsible for performing the sensing function and transmit their sensory data to closest DRNs. Where, DRNs perform data gathering for the data generated from BANs. The distance between these nodes is specified by the communication range of the networking MAC protocol used. Subsequently, DRNs nodes transmit their data to DDNs which is in charge of transmitting the collected data to the Network control centre. Figure 1 shows the hierarchical relationship between the different types of nodes in the networks. The technology which can be used to discharge the data from DDNs to the network control centre can vary such as Satellite cellular technology.

![Hierarchical Representation of Linear Structure Sensor Network](image)

**Figure 1.** A hierarchical representation of the linear structure sensor network

In providing energy efficiency and avoid hotspot problem in LWSN, the authors in[18] proposed node placement scheme for LWSN. In this scheme, network is divided into multiple distribution points which can be represented as clusters and there is one cluster head (CH) in each. The optimal spacing between each distribution points calculated and it shows that the distance between the distribution points is getting closer as distance to the BS getting close. In addition, optimal density of nodes in each distribution point is found and it shows that the differences between the numbers of nodes in each distribution point is very smaller relatively to the distance from BS. To reduce the communication distance in LWSN, a new liner cluster handling (LCH) technique towards energy efficiency in LWSN with multiple static sink is proposed [19]. Authors assumed that a single static sink in LWSN reduces the lifetime and throughput of the network. Therefore, three statistic sinks and clustering method are used to provide energy efficiency. Also, network topology is divided into four equal regions and equal number of nodes. Sinks are distributed into two at the corner and one at the centre of the network. Moreover, CH is formed in each region to ultimately reduce the energy consumption and the communication distance. CH is selected randomly. Subsequently, CH performs data aggregation for the data received from member nodes and then transmits data to the nearest sink to it. In [20], the authors proposed a Reliable and Energy-efficient Chain-cluster based routing protocol (REC). This protocol aimed to provide a multi-hop reliability and energy efficient. The operation of routing protocol is divided into three phases where in the first phase the network is divided into multiple clusters and this is done by base station (BS). Subsequently, in the second BS selects the node with the maximum link reliability and energy is selected as cluster head. Proper cluster size is also taken into consideration in REC to provide a load balancing between the clusters. Moreover, to ensure a reliable
data transmission between CHs and sensor nodes, BS associates the nodes to CHs according to link reliability between them. After the end of the cluster head selection and node association phase, the chain cluster formation is constructed between the CHs. The CH which has highest energy and can communicate directly with the base station is selected as Chain head. Also, in case of any CH cannot communication with next CH, relay node is introduced to works intermediate node between the two CHs. However, results of this protocol shows that REC outperforms a number of approaches such as LEACH and PEGASIS protocol.

While in MDC based LWSN , researchers in [5] proposed a mobile data collection (MDC) based LWSN where mobile node visits every sensor nodes in the network and perform data collection from sensor nodes and then carry the data collected to the sink. Mobile node can be easily deployed and utilized for data collection in LWSN as the network takes a liner thus the route the need to followed by Mobile node is already known while others topologies such as mesh mobile node needs to communicate with sensor nodes to specify the followed route. Also, another work for using mobile data collection is presented in [3],[21] where authors proposed to use Unmanned Aerial Vehicles (UAVs) for data collection in LWSN. In their works, different nodes types are referred as sensor nodes (SNs), relay nodes (RNs), UAVs, and sinks as shown in figure 2.

![Figure 2. The various nodes at the different levels](image)

Each type has specific function and role. The first type is sensor nodes (SNs), these nodes represent the ordinary sensor nodes in the network. SNs transmit the sensed data to the nearest RNs. Communication between RNs and sensor nodes is done either directly or in multi-hop form, where RNs nodes act as cluster heads that collect data from the ordinary sensor nodes. Subsequently, RNs communicate with UAV for data discharging when it comes in its communication range. UAV carries the data collected from all RNs to the Sink node which in charge to transmit the collected data to the network control centre. However, different speeds for UAV are utilized to experiment the end-to-end delay, buffer overflow of RNs.

5. Discussion and future trends

Using sensor nodes in critical infrastructure protection applications such as pipeline for gas and oil requires a high reliability and a long life working for sensor node. As reliable data collection in LWSN plays an important role in success of the event detection application which requires collecting all the data without loss. For example, an event of moving any object in border monitoring system must be reported to the network control centre so that an action can be taken. Data collection LWSNs is categorized into multi-hop approach and MDC approach in previous section. Each approach has its own cons and pros. The table below summaries the pros and cons in term of energy efficiency, delay and packet dropped.
Table 1. Comparison between Multi-hop and MDC

| Approach | energy consumption | end-to-end delay | packets drop |
|----------|--------------------|------------------|--------------|
| multi-hop | Medium             | Low              | Medium       |
| MDC      | Low                | High             | High         |

From Table 1, it can be seen that using multi-hop approach could lead to deplete the energy of sensor nodes quickly in LWSN as network topology could be extended to hundreds of kilometres and data packets need to be routed all long way in order reach the base station while using MDC could prolong the network lifetime and reduce the energy consumption. However, LWSN based MDC can result in significant end to end delay as also the UAV needs to collect data either from each sensor nodes individually or from RNs, as routing the data packets in multi-hop form can lead to reduce the end-to-end delay and packets drop. In MDC, sensor nodes require to keep the data packets in their buffer till UAV comes within their communication range and this can results in buffer overflow due to the limited memory capacity of sensor nodes. To enhance data collection in LWSN and solve the above issues, there are some future trends for both approaches, which are listed as follows.

- For multi-hop approach in LWSN, it is very good to reduce the distance of network by using multiple sink nodes so that the hotspot problem will be avoided and this can also reduce the number of hops which leads to reduce the energy consumption. For example in [19] multi-sink technique is used, but the CHs selection mechanism is performed randomly which can reduce the network lifetime, therefore using multi-sink with [22] where as CHs selected according to different parameter can provide better network performance. Also, sensor nodes may suddenly suffer from energy depletion or hardware damages and this result in disturb the connectivity of network especially in multi-hop approach where there is no alternative route. Therefore, a fault tolerance scheme in this work should be considered.

- MDC approach offers a better performance in term of energy consumption, but high end-to-end delay and number of packets dropped. Therefore dividing the network into multiple areas and deploying one UAV for each area can enhance the data collection in LWSN. Also, it is very necessary to take into consideration the speed of UAV as a parameter while dividing the network into multiple areas. In addition, packets dropping caused by buffer overflow reduces the reliability of monitoring system thus using a buffer management algorithm like in [23] could solve this problem.

- To provide energy efficiency and avoid hotspot problem with minimum end-to-end delay data collection in LWSN, hybrid approach can be used such as[24]. In this hybrid approach, data collection is done using both mobile data collection and multi-hop approach which results in better performance from using each approach individually.

6. Conclusion
The liner structure form of sensor nodes in applications like pipelines and bridge monitoring system and the long distance topology pose some challenges in data collection from sensor nodes. Recent works for data collection in LWSN were based on either Multi-hop approach or MDC. The Multi-hop approach, showed a good results in term of end-to-end delay and packets delivery ratio, but it is very costly in term of energy consumption while minimum energy consumption and significant end-to-end
delay and packets dropped when using MDC. Therefore, some future trends are suggested such as using multiple sink nodes, deploying multiple UAVs and hydride approach aimed to improve the data collection in LWSN.

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