Study of multiple-source data collection in wireless sensor networks

Radhi Sehen Issa
Faculty of Engineering, Al Mustansiriya University, Iraq

Article Info

Article history:

Received Dec 28, 2018
Revised Jan 21, 2018
Accepted Feb 27, 2019

Keywords:

Discovery
Network
Routing
WSN

ABSTRACT

A detailed survey on the process of data collection from multiple sources in Wireless Sensor Networks (WSNs) is introduced. The topologies that determine the location of the network components with respect to each other are presented. These topologies are often referred to as Mobility topologies. The performance of the overall WSN architecture significantly depends on these topologies. As a consequence, these topologies are elaborately compared and discussed. The most common network components that efficiently collaborate in data collection process are explained. To highlight the data collection process as a subject of our concern, the phases that describe the stages of the data collection are illustrated. These phases consist of three successive stages: discovery, data transfer, and routing. To sum up, the most recent approaches for developing the process of data collection in multiple-source WSNs are also presented.

Corresponding Author:

Radhi Sehen Issa,
Faculty of Engineering,
Al Mustansiriya University,
Baghdad, Iraq.
Email: aliramy102@yahoo.com.

1. INTRODUCTION

Because of their indispensable benefits in a wide range of applications, Wireless Sensor Networks (WSNs) have recently become the state of art technology in several areas of our daily life demands. For instance, they are extensively used in monitoring applications (health care, pollution avoidance, and modern agriculture methods), surveillance (security threads and tracking of targets), and detection purposes (natural and man-made disasters) [1], [2].

From design perspective, a WSN usually comprises of a huge number of very small devices called sensor nodes. These devices are run via batteries and mainly perform the following functions:

a. They capture/collect the required data in terms of analog signals from the surrounding space.
b. They store the attained data and process them according to a pre-prepared mechanism.
c. They wirelessly transfer these data to data-collection nodes or sometimes referred to as sink nodes [3],[4].

2. WSNS ARCHITECTURE'S TOPOLOGY

From network architecture perspective, WSNs' sensors can operate either in static or mobile topology. The static topology is the most common architecture which is mainly characterized by a dense design, i.e. the WSNs have multiple hop paths. This topology offers simplicity in terms of network control and data availability. On the other hand, the mobile topology is more preferable than the static topology for several various reasons [5]:

a. Cost-effective topology: because of the mobility feature of the cooperative sink nodes, the number of the required nodes in a specific area is decreased. As a consequence, the overall cost of the WSN architecture is dramatically reduced. The cost can further be reduced by making use of the mobile elements such as cars and buses already available in the intended area.
b. Energy-efficient topology: In the traditional/static sensor nodes, the collected data are transferred from the furthest active nodes in the sensing area to the sink nodes through multiple hops. To clarify this, the data are transferred from the source nodes to the destination nodes via intermediate nodes which only forward the data traffic without performing any extra processing to these data. The closer the data are to the sink nodes, the more data traffic is centered on these destinations. In other words, most of the traffic is usually concentrated in the sensor nodes surrounding/closest to the sink nodes. As a result, a non-uniform energy-consumption map is formed which describes the rate at which the energy is being consumed by the sensor nodes along the static WSN architecture. This phenomenon is called the effect of funneling in which the sensor nodes around the sink nodes suffer from the problem of traffic bottleneck. This may lead to degradation in terms of the network lifetime, connectivity, and data transfer rate as the number of paths hops increases. Nevertheless, the mobile sensor nodes can significantly reduce the energy consumption and lead to a more uniform and balanced consumption map. This also leads to improvement in terms of lifetime, data rate, and throughput of the network [3].
c. Reliability: as the traditional static WSN is dense and the number of hops paths is relatively large, the probability of data collisions occurrence increases. Consequently, the loss of the collected data increases because of the fact that the data loss is directly proportional with the number of hops in the network. Therefore, the network reliability is degraded. Alternatively, the mobile sink nodes can directly collect data from anywhere in the network; as a result, only one single hop is required for transmitting the collected data. Thus, the number of collisions is considerably reduced as well as the data loss.
d. Connectivity: because of the mobility feature of the mobile sink nodes, a dense network is not needed anymore. In addition, isolated areas located far away from the intended sensing area can now be reached and discovered. Therefore, the constraints regarding the location and the size of the sensing zone intended are not taken into consideration anymore [1].

However, some challenges should also be taken into consideration when choosing the mobile elements in the design of the WSNs. The main challenges can be explained as follows:

a) Power management: for optimum power consumption, the data collection/awakening times of the sensor nodes should be known or at least predicted. This can be achieved by accurately expecting the times at which the mobile elements are located within the sensors nodes' transmission range.
b) Efficient transfer: to ensure that all the necessary data are obtained, the percentage of the messages data perfectly-transferred to the sink nodes should be maximized. Furthermore, and for effective data transfer/exchange with minimum loss, awareness regarding the nodes' mobility speed and mechanism should be considered during the design phase of the WSN architecture [6].
c) Control: in mobile topology, design parameters such as nodes' mobility speed and mechanism impose a challenge on the network designers if these parameters can be controlled. Accordingly, the mobile nodes' speed and paths should be optimized for maximum network performance [4], [7].

3. WSNS' MAIN COMPONENTS

In order to have a deep insight about data collection by multiple sources in WSNs, it is better to introduce the main network components contributing to the data collection process. The main components can be listed as follows:

a. Sensor nodes: the main function of this component is sensing the surrounding changes/phenomena for which these nodes are designed. Therefore, they are considered as the main source of data/information in the WSN. Moreover, these nodes can also serve in messages forwarding or rebroadcasting processes in the network [5].
b. Sink nodes: the main task of this component is collecting the data obtained by sensor nodes, i.e. they are considered as the destination of data/information. That's why these nodes are sometimes referred to as base stations. The data sensed by sensor nodes are being collected by sink nodes either via visiting the sensor nodes (direct mode) or via mediator nodes located within the whole WSN (indirect mode). The collected data can either be made use of them independently by these sink nodes inside the WSN itself or be made available to users located outside the WSN who can get benefit from these collected data.
c. Support nodes: these nodes support the network processes including, for instance, carrying out the role of mediator nodes, gateways, or secondary data collectors. Thus, these nodes are neither considered as data

sources nor data destinations. This also implies that these nodes may or may not present in the WSNs depending on the design and the requirements of the network [3].

It should be mentioned that the network components mentioned above can all be mobile, static, or a combination of both of these topologies depending on the network specifications and design requirements [7].

After the above explanations regarding the operation principals, WSN architecture's topology types, and the main network components associated with the multi-source WSN, the process of data collection is described in more details in the following section.

4. DATA COLLECTION PHASES IN WSNS WITH MOBILE TOPOLOGY

The different phases of data collection process are explained in this section with a focus on multiple-source WSNs with the mobile topology. To start with, and to guaranteed the occurrence of the collection and transfer of data successfully among the different network components, a wireless communication paradigm called "contact" should perfectly take place. To illustrate this, Figure 1 can be considered. In this figure, the network component denoted by "Mobile element" is said to be "in contact" with other components provided that these network components are located within their mutual coverage range. Accordingly, the time period that the components spent being in contact with each other is called "contact time", and the zone through which the components are perfectly in contact is called "contact area" [8], [9].

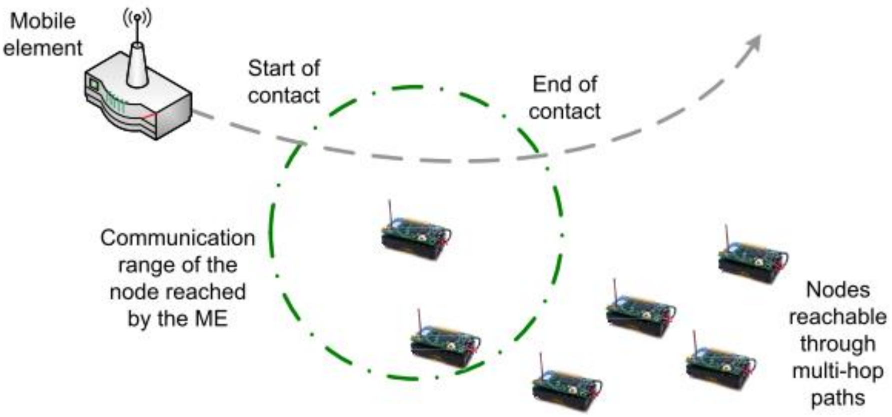

Figure 1. Illustration of data collection process in WSN with mobile topology [3]

For the aforementioned, it is implied that the network components cannot literally transfer data with each other if these components are not in contact. That is, the node first inspects the existence of a mobile element within its coverage range. This is commonly referred to as "Discovery" process, which can be demonstrated as follows:

Discovery: it is the first phase of the data collection process in the multiple-source WSNs. The purpose of the discovery protocols in the WSNs is to sense the presence of contacts once they are in the nodes coverage area. In other words, the time spent by the nodes to discover the contacts, called "discovery time", should typically be minimized to a minimum possible value. This generally contributes in three benefits. The first is reducing the energy consumption of the overall WSN architecture. The second benefit is maximizing the potential number of discovered contacts which helps in improving the network performance. The third benefit is maximizing the time interval spent by the network components in exchanging the data/information. This time interval is referred to as "residual contact time" and usually less than the contact time previously mentioned. Hence, the contact time can be expressed as follows [10]:

$$\text{Contact Time} = \text{Discovery Time} + \text{Residual Contact Time} \quad (1)$$

To further illustrate the residual contact time, the next/second phase of the data collection process is now introduced:

Data Transfer: once the contacts are discovered by the nodes and these network components are in contact, the data transfer phase starts. This phase directly follows the discovery phase, and the data exchange process takes place during this phase. The aim of this phase's protocols is exploit the residual contact time as much as possible, i.e. to enhance the network throughput. This is mainly achieved via maximizing the number of messages perfectly exchanged among the network components. Meanwhile, this may also lead to minimizing the network energy consumption [5].

The last step in data collection process is to deliver the message / information to the final destination. This step is often referred to as "Routing", which is explained as follows:

Routing: it is the last phase of the data collection process in the multiple-source WSNs. In this phase, the optimum paths and support nodes are selected for data forwarding to the sink nodes, mobile element or the node which is in contact with that mobile element. This in turn results in decreasing the energy expenditure and improving the data delivery/transmissions rate in the whole WSN. The mechanism of routing protocols and processes differs according to the multi-source WSN architecture's density. To clarify this, for a dense WSN, the data routing to the destination can always be accomplished due mainly to the multiple-hop paths. On the other hand, for a relaxed WSN, the nodes are somehow arranged into separate groups. These groups are usually referred to as "clusters" in which the routing happens if the mobile element and at least one of the nodes in one of these clusters are in contact. In case the mobile element and/or the cluster nodes are far away from each other or the sink nodes, some of the other nodes located outside the clusters are selected as support nodes to act the role of gateways/bridges between the mobile element and the cluster nodes [3].

Figure 2 shows the mobile topology of data collection process in WSN.

Figure 2. Mobile topology of data collection process in WSN

5. ADVANCES IN MULTI-SOURCE DATA COLLECTION IN WSNS

As mentioned earlier in the WSNs architecture's topology, the mobile topology has the upper hand priority especially in terms of reducing the energy consumption of the whole WSN architecture. This merit for the mobile topology can be further improved via devising new effective transmission strategies. The reason behind choosing this methodology for reducing the energy consumption is mainly attributed to the fact that the majority of the total energy consumption of the overall network is being consumed by the transmitted and received data. Accordingly, many solutions have been proposed to address this issue [8]. Multi input multi output technique was proposed by [10] to collect the mobile data from multiple sources. Another technique is adopting collaborative divergence employing coding of the WSN to enhance the system reliability [8]. Another new technique based on utilizing coded collaboration and multiple source collaboration in mobile-based WSNs was also developed [1].

6. CONCLUSION

A study on data collection process in Wireless Sensor Networks (WSNs) using multiple sources with a focus on the mobile topology was presented. The static topology is preferred when specific features such as simple network control and data availability are desired. On the other hand, the mobile topology is attracting increasing interest due mainly to the fact that this topology outperforms the static in terms of energy expenditure, reliability, cost, and connectivity. Main network components represented by sensor, sink, and support nodes can all be mobile, static, or a combination of both of these topologies depending on the system requirements. For the collected data to be successfully transferred among the network components, the mobile element should perfectly be "in contact" with other network nodes. To explain this, the nodes first discover the mobile elements presence in their coverage range. Then, data transfer/exchange process takes place, which mainly aims to maximizing the network throughput though maximizing the number of perfectly delivered messages and minimizing the energy consumption. After that, optimum paths and support nodes are selected for data forwarding to the destinations. This ultimately helps in reducing energy consumption and the data delivery time to the destinations. Finally, several techniques have been proposed in literature in order to improve the data gathering process in WSNs through multiple sources.

REFERENCES

[1] C. Han and J. Yang, "Multi-Source Cooperative Data Collection with a Mobile Sink for the Wireless Sensor Network," *Sensors*, vol. 17, p. 2493, 2017.

[2] C. Konstantopoulos, G. E. Pantziou, D. Gavalas, A. Mpitziopoulos, and B. Mamalis, "A Rendezvous-Based Approach Enabling Energy-Efficient Sensory Data Collection with Mobile Sinks," *IEEE Trans. Parallel Distrib. Syst*., vol. 23, pp. 809-817, 2012.

[3] M. D. Francesco, S. K. Das, and G. Anastasi, "Data Collection in Wireless Sensor Networks with Mobile Elements: A Survey," *ACM Trans. Sen. Netw*., vol. 8, pp. 1-31, 2011.

[4] V. C. Gungor and G. P. Hancke, "Industrial wireless sensor networks: Challenges, design principles, and technical approaches," IEEE Trans. Industrial Electronics, vol. 56, pp. 4258-4265, 2009.

[5] S. Chen, M. Coolbeth, H. Dinh, Y.-A. Kim, and B. Wang, "Data Collection with Multiple Sinks in Wireless Sensor Networks," Berlin, Heidelberg, 2009, pp. 284-294.

[6] Y. Yu, B. Krishnamachari, and V. K. Prasanna, "Issues in designing middleware for wireless sensor networks," *IEEE network*, vol. 18, pp. 15-21, 2004.

[7] M. I. Khan, W. N. Gansterer, and G. Haring, "Static vs. mobile sink: The influence of basic parameters on energy efficiency in wireless sensor networks," *Computer Communications*, vol. 36, pp. 965-978, 2013/05/15/ 2013.

[8] O. Valle, C. Montez, G. Medeiros de Araujo, F. Vasques, and R. Moraes, "NetCoDer: A Retransmission Mechanism for WSNs Based on Cooperative Relays and Network Coding," *Sensors*, vol. 16, p. 799, 2016.

[9] R. Alattas, "Detecting black-hole attacks in WSNs using multiple base stations and check agents," in Future Technologies Conference (FTC), 2016, pp. 1020-1024.

[10] D. Liu, K. Zhang, and J. Ding, "Energy-efficient transmission scheme for mobile data gathering in wireless sensor networks," *China communications*, vol. 10, pp. 114-123, 2013.