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Optimizing Latency and Energy Consumption in Wireless Sensor Networks: A Review

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ABSTRACT: With the advancements in interconnected devices and automation, wireless sensor networks have gained substantial importance. One of the major challenges which wireless sensor networks face is the constrained energy. Moreover, to enhance the effectiveness, it is necessary to reduce the latency as much as possible. There are several protocols which are followed to optimize the latency and the energy consumption of wireless sensor networks with their own pros and cons. This paper presents a comprehensive review of the different aspects related to wireless sensor networks along with the relevant approaches. The paper should pave the way for an optimized routing protocol to satisfy the aims of latency and network lifetime.

Keywords: Wireless Sensor Network (WSN), Latency, Clustering, Network Lifetime, Energy Consumption.

I. INTRODUCTION

The WSN consist of huge amount of sensor nodes to sense some physical condition. The capabilities of tiny sensors is increasing, in term of sensing and processing data, and communicating, enable the implementation of WSNs, which is based on aggregate effort of huge amount of tiny sensor nodes [2]. WSNs have very wide range of applications. With advancement in WSNs, they are going be an integral part of our daily life. In correct sense to utilize the prospective applications of WSNs, an efficient and highly sophisticated wireless data transfer protocols are needed. As WSNs have large amount of sensor nodes to sense some physical or environmental condition. In order to get reliable observation and to take correct decisions, the physical phenomena or environmental condition must be reliably sensed by sensor nodes. The sensor nodes should capability to process the sensed data and send only processed data as sensor nodes have huge amount sensed raw data. The protocols should have self-organizing capabilities so that efficient use network is possible. The basic architecture of a sensing module is depicted in the figure below:

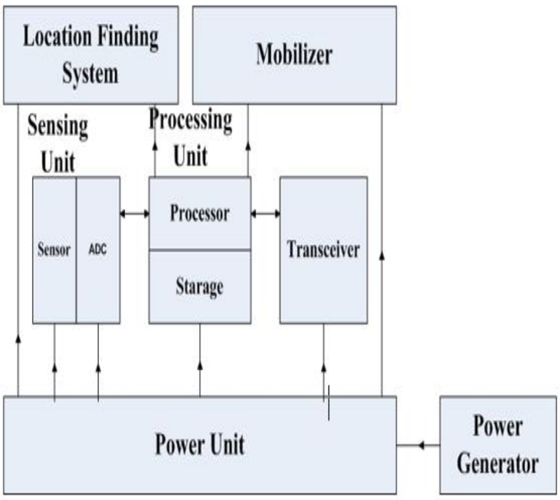

Fig.1 Basic Architecture of Wireless Sensor Network

The basic components of WSN nodes are:

1) Sensing unit,
2) Processing unit,
3) Transceiver unit
4) Power unit.
5) Mobilizer and Location Finding Unit

The sensing module is basically an amalgamation of the analog sensor which senses the analog data such as temperature, pressure etc. However, there is a need to convert the data into digital format which needs the analog to digital converter. The ADC processes the data and converts the data to be compatible with digital formats. There also exists a processor which processes the data and has a storage capacity in the memory. The data may be needed to be help for a while prior to transmission.

The transceiver is of fundamental importance which is responsible for the transmission and reception of data packets. The power unit is generally operated via batteries since it's not feasible to operate a line wired power source to the sensing module. The battery operated sensing module imposes the limitation of the power consumption and the network lifetime. This puts a fundamental necessity on the system of attaining a high network lifetime.

The mobilizer and position finding system are optional modules in the WSN. It may be needed to locate the sensing module at times and change its position. The position finding system does the work of finding the position of the sensing module and relaying the information to the control station. Typically, servo motors etc. are used as mobilizers. This however may be optional in WSNs.

II. ENERGY CONSUMPTION AND LATENCY IN WSNs

If we consider an ideal situation, then all the nodes in the network can be assumed to be distributed uniformly. They would however have different individual lifetimes. Thus average energy for round k can be given by $\bar{E}(r)$ of rth round is as follow:

$$\bar{E}(k) = \frac{1}{L} E_{Tot}\left(1 - \frac{k}{R}\right) \qquad (1)$$

Here,

R is an indicative of the aggregate rounds of the lifetime of the WSN.

M is the total number of transmissions

L is the number of nodes.

The latency in the Network is given by:

$$L = \frac{1}{n}\sum_{i=1}^{n} T_i^S - T_i^r \qquad (2)$$

Here,

L is the average latency

n is the number of nodes

T_i^S represents the time at which data is sensed by node i

T_i^r represents the time at which node i's data is received by data sink

It is always desirable to reduce the latency and the average energy of the WSN so as to improve the performance and the network lifetime.

III. RELATED WORK

The following section summarizes some of the prominent work in the field of WSNs in a chronological order. It can pave the path for further improvements in the field.

In IEEE 2018, [1] Huang et al. proposed a technique named (FRAVD). In this approach, the data transmission from the sensing module to the control station is done based on the multi hop relaying approach. In this approach, relay nodes are chosen such that the latency for the data to travel from the sensing module to the control station is minimized. The variation of the network lifetime and the energy consumption is also computed with respect to the duty cycle of the system.

In Elsevier 2018, [2] Nan Cen et al. presented the idea of LANET: which stands for visible light mobile ad-hoc networks. The data transfer in this case was in the form of visible frequencies. It was shown by dint of the experimental set-up that the proposed system was capable of increasing the network lifetime.

In IEEE 2018, [3] Yuxin Liu et al. proposed the QTSAT model. This was primarily used for the delay minimization in wireless sensor networks. The system was basically developed using the MAC protocol for the WSNs. Power consumption was not the primary focus of the paper and throughput enhancement was targeted.

In Elsevier 2017, [4] Quing Liu et al. proposed a technique for the implementation of unicast-broadcast mechanism for WSNs. It was shown that often, unicast mechanisms in a broadcast network can provide more energy saving compared to conventional techniques.

In Elsevier 2017, [5], Kgotlaetsile Mathews et al. proposed a technique for software defined radio (SDR) concept for wireless sensor networks. It was a new approach for the design of Software Defined (SD) based WSNs.

In IEEE 2017, [6] Cheng Zhan et al. presented the concept of UAV based technique. The idea was to increase the lifetime and decrease the delay latency of the network by switching to the UAV technology of the network. The evaluation parameters were the network lifetime and average delay.

In IEEE 2016, [7] Yuxin Liu et al. proposed a technique for secure and trustworthy techniques for data routing in WSNs. The approach evaluated the chances of data theft in Wireless Sensor Networks in the absence of strong encryption algorithms which may not be practically possible in real life situations due to the limitations of the sensor module.

In IEEE 2016, [8], Ju Ren et al. evaluated the lifetime and energy holes in Wireless Sensor Networks. The technique tried to evaluate the free spectrum and term it as a hole to avoid data congestion in the WSN.

In IEEE 2016, [9], Mianxiong Dong et al. presented a concept to increase the lifetime and also decrease the delay in wireless sensor networks. The approach was tested under the constraints of reliability constraints of the WSN architecture. This approach was practical in the sense that WSNs are seldom highly reliable.

In IEEE 2015, [10] Abdul Waheed Khan et al. presented a VDGRA based approach in which a virtual grid based approach was used. The evaluation of the system was done based on network lifetime. It was shown that the proposed approach could attain a network lifetime of around 800 rounds of data transfer for a node count of 400.

In 2015 IEEE, [11] Juan Luo et al. put forth opportunistic algorithm approach for wireless sensor networks. It was shown that ss the network lifetime is of a key importance for the performance of the wireless sensor network, improvement and its enhancement can be very beneficial.

In IEEE 2015, [12], Yanjun Yao et al. presented a WSN architecture for delay minimization and lifetime enhancement in heterogeneous networks. It was shown that with Link heterogeneity one can get huge information transmission range easily. As it is more bound towards the link and connectivity framework it yields better and reliable links and connection paths for routing.

In IEEE 2014, [13] Shuo Guo et al. presented an opportunistic flooding in WSNs. It was proposed that the routing and information exchange must be designed diligently such that the entire functions consume minimum power.

In IEEE 2014, [14], Changlin Yang et al. proposed a Complete Targets coverage in Energy Harvesting based approach for WSNs. It was shown that the connectivity metric is of enormous use as it decides the protocol of the information transmission.

In IEEE 2014, [15], Ismail Butun et al. presented an intrusion detection mechanism for wireless sensor networks. The approach was targeted at detecting the chances of possible attacks in WSNs.

S.No	Work/Reference	Authors	Approach
1.	Reference [1]	Mingfend Huan et al.	The proposed technique named (FRAVD). In this approach, the data transmission from the sensing module to the control station is done based on the multi hop relaying approach and energy consumption is minimized along with low latency approach.
2.	Reference [2]	Nan Cen et al.	Authors presented the idea of LANET: which stands for visible light mobile ad-hoc networks. The data transfer in this case was in the form of visible frequencies.
3.	Reference [3].	Yuxin Liu et al.	The appraoch was primarily used for the delay minimization in wireless sensor networks. The system was basically developed using the MAC protocol for the WSNs.
4.	Reference [4]	Qing Liu, et al.	Authors proposed a technique for the implementation of unicast-broadcast mechanism for WSNs and could provide more energy saving compared to conventional techniques.
5.	Reference [5]	Kgotlaetsile Mathews et al.	Authors proposed a technique for software defined radio (SDR) concept for wireless sensor networks. It was a new approach for the design of Software Defined (SD) based WSNs.
6.	Reference [6]	Cheng Zhan, et al.	The approach used was to increase the lifetime and decrease the delay latency of the network by switching to the UAV technology of the network.
7.	Reference [7].	Yuxin Liu, et al.	The approach evaluated the chances of data theft in Wireless Sensor Networks in the absence of strong encryption algorithms which may not be practically possible in real life situations due to the limitations of the sensor module
8.	Reference [8]	Ju Ren, et al.	The technique tried to evaluate the free spectrum and term it as a hole to avoid data congestion in the WSN.
9.	Reference [9]	Mianxiong Dong, et al.	The proposed appraoch was tested under the constraints of reliability constraints of the WSN architecture. This approach was practical in the sense that WSNs are seldom highly reliable.
10.	Reference [10].	Abdul Waheed Bangash et al.	Authors presented a VDGRA based approach in which a virtual grid based approach was used. The evaluation of the system was done based on network lifetime.
11.	Reference [11]	Juan Luo, et al.	Authors put forth opportunistic algorithm approach for wireless sensor networks.
12.	Reference [12]	Yanjun Yao1, et al.	Authors presented a WSN architecture for delay minimization and lifetime enhancement in heterogeneous networks. It was shown that with Link heterogeneity one can get huge information transmission range easily
13.	Reference [13]	Shuo Guo, et al.	Authors proposed an opportunistic flooding in WSNs. It was proposed that the routing and information exchange must be designed diligently such that the entire functions consume minimum power.
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			the connectivity metric is of enormous use as it decides the protocol of the information transmission.
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Table.1 Comparative Analysis of Previous Work in the Domain

The summary and comparative analysis of the different approaches renders insight into the common approaches employed to increase the network lifetime and reduce the latency.

IV. EVALUATION PARAMETERS

The evaluation parameters for the performance evaluation of the WSN are:

Energy Consumption

The energy consumption also depends on the duty cycle which is given by:

$$DC = \frac{1}{K} \quad (3)$$

Here,
DC represents the duty cycle.
K is the number of nodes among which a CH is selected.
It can be clearly inferred that as the value of K increases (duty cycle decreases), the number of nodes for which one CH is chosen also increases. This clearly decreases the energy consumption i.e. the energy consumption decreases with decrease in duty cycle and increases with the increase in the duty cycle i.e.

$$Energy\ Consumption = f\ (DC) \quad (4)$$

One Hop Delay

Moreover, as the cluster size increases, i.e. K increases (DC decreases), the one hop delay of the system increases which is nothing but the delay the data packet takes for a single hop transmission. Thus decrease in DC increases one hop delay and increase in DC decreases the one hop delay.

Network Delay

The network delay is often computed w.r.t. the distance from the sink. Clearly, as the distance from the sink increases, the time required for the data to reach the base station also increases i.e.

$$ND = f(d_{sink}) \quad (5)$$

ND is the network delay
f stands for a function of
d_{sink} is the distance of the nodes from the sink

Energy Consumption and Residual Energy of nodes w.r.t. distance from sink

In case the node is far away from the sink, its chances for a long distance transmission reduces, hence it would transmit to a nearby node, thereby reducing the energy consumption. This would in-turn increase the residual energy of the nodes.
Thus as the distance from sink increases, the energy consumption decreases and the residual energy increases. Thus,

$$E_C = f(d_{sink}) \quad (6)$$

$$E_{Residual} = f(d_{sink}) \quad (7)$$

Thus two important considerations have been seen which are conserving the energy of the system so as to increase the network lifetime and moreover increasing the efficacy with which the packets are transmitted and received by the transmitting end and the receiving end. This would in turn increase the latency performance of the system by reducing the da=delay of the system. The formulations above give the relation among various variables for the computation of the same.

V. CONCLUSION

It can be concluded from the previous discussions that it is critical to minimize the latency and the energy consumption of wireless sensor networks. This is primarily important since low network lifetime results in low efficiency of operation of WSNs as the system needs to shut down frequently. Moreover, another critical aspect is the delay or the latency which also needs to be reduced as much as possible. The paper presents a comprehensive review of the contemporary approaches in the domain so as to render insights into upcoming ideas.

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