Linear Regression based Power Optimization of Wireless Sensor Network in Smart City

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Abstract. The modern smart cities are highly dependent on the performance of the Internet of Things (IoT) based energy-efficient sensor networks. Energy efficiency is a critical and indispensable issue for wireless sensor networks (WSNs). In the collection of sensor nodes, one node is selected to collect data and forward it to the base station. The modern base stations in smart cities are unmanned aerial vehicle (UAV) based. This paper presents a linear regression based model, where the initial residual energy and its corresponding transmission power are submitted to the proposed system, then it generates a prediction model since transmission power depends on the residual energy of the sensor node. Based on this model the transmission power of the sensor node can be calculated for data transmission as a higher residual node is best suitable for data transmission to the base station. As presented in the simulation result, the regression based model gives better performance for energy efficiency in WSN.

1. Introduction
With the population growth and development in surrounding urban regions, the cities should be smart. The services beneficial to society, environment, and economy, are provided by the smart city [1]. These smart city services are significantly interactive, energy and cost-efficient, and more aware in security monitoring. The modern smart city deployments have concentrated on wireless sensor networks (WSNs) based Internet of Things (IoT) to improve the infrastructure efficiency [2]. The complete infrastructure of smart city contains various smart components as presented in Figure 1, it facilitate smart homes [3], smart agriculture [4], smart transportation [5], smart industry [6], smart energy and environment [7], smart health care [8], and many more smart services and applications [9]. So all these are the indispensable constituents to built and develop a smart city. Smart homes provide efficient electricity management for appliances, security cameras, and waste management. Smart agriculture facilitates weather monitoring systems, technology based farming, control of climate changes, water level control, etc. Smart parking, traffic monitoring, logistic, and accident alert systems are provided by a smart transportation system. The modern industry 4.0 [10] highly depends on smart industry and industrial internet of things which uses machine monitoring, smart warehouse, stock, and retail management. Smart power control, earthquake detection, fire control and safety, air quality monitoring, etc. are envisioned by smart energy control and environmental monitoring system. Smart health care...
system provides patient monitoring, Internet of medical things (IoMT), emergency services and wearable body sensor network (BSN) [11, 12, 13, 14].

![Figure 1. Various Components of Smart City](image)

Concerning wireless sensor network, a smart city contains huge number of heterogeneous sensing and IoT devices. Due to high quantity of sensors connected to IoT network, a vast amount of data is accumulated to the server. The sensor network of smart city is high expandable so new type of several heterogeneous devices can be connected and old unused devices can be removed or repaired in the network [15]. A wide rage of applications are possible in WSN, so the arrangement on different kinds of geographical topologies of sensing nodes and IoT devices are challenging task [16]. The concept of smart city can not be envisaged without energy efficiency, so center point of this paper is the energy efficiency of smart city based WSN. However, the network of IoT devices with collaboration of UAVs create magnificent architecture for future smart city [17].

The section 2 presents surveys and works on energy efficiency issues in WSN for smart city, section 3 explains the proposed system model where linear regression based prediction shows how sensor nodes are selected to transmit data based on its residual energy for efficiency of WSN, section 4 presents the comparative simulation result of proposed system and finally section 5 concludes this research work with future aspect and enhancement.

2. Related Work
The limitation and constraint of energy resource in various sensor networks for smart city applications, many researchers have presented variety of techniques for raising energy efficiency in wireless sensor network (WSN).

Marrero et al. [18] presented a novel energy optimization method in the wireless backbone network for smart city. Their mechanism for energy saving also permit to develop a portable type of wireless backbone network which can be applied in various applications and places. For the mesh access point, at the time period of inactive or idle condition of wireless interface, they revealed an critical reduction in power consumption. They formulated an algorithm to manage the state transitions of radio interfaces in the mesh access point that saves and minimizes the overall power consumption of sensor nodes by interoperability of wireless mesh network.

Shafieirad et al. [19] analyzed the maximization problem of data quality in “Energy Harvesting Wireless Sensor Network (EH-WSN)”. The progressive research and development in smart cities acquire analysis of these networks crucial and important. For smart city, a practical oriented framework for wireless sensor network based application is presented in this
Research. They proposed a realistic large scale efficient energy-harvesting aware routing scheme for the maximization problem of data quality in wireless sensor network.

Sirsikar and Chandak [20] proposed a framework called “self-organized wireless sensor network (SOWSN)” and developed two-hop clustering based protocol for residual energy of sensor nodes. To analyze the performance, they compared their proposed protocol for average energy consumption calculation using various sensor nodes at distinct ranges of transmission. The outcomes represent that proposed protocol is capable to minimize the energy consumption and enhances lifetime of the network. When the quantity of sensor node is raised, then it minimizes the energy consumption at specific range, that presents the network scalability.

Fialho and Fortes [21] presented a IoT based smart city application using network of low power sensor nodes. Based on long range (LoRa) protocol, in this communication system, interconnection is established from end nodes to the gateway with 1% of duty-cycle. Using 2 dBm of minimum transmission power at gateway, LoRa communication of minimum 5 km based on radio frequency can be accomplished. Due to obstacle created by line of sight from end node to the gateway, RF signal attenuation is raised along with decreases of distance. So the end node should enhance the spreading factor (SF) to reach the desired distance for power optimization.

Liu et al. [22] proposed an efficient energy beamforming for “RF energy-harvesting wireless powered sensor networks for smart cities” with time assignment. In this approach, initially sensor nodes harvest the energy from their associated sink node, then they transmit accumulated data into the sink node by time-division multiple access (TDMA) using those harvested energy.

Jabbari et al. [23] proposed “energy efficient linear sensor (EELS) infrastructure” for smart city applications. In this structure, they provided different linear sensor nodes with services and support of Internet of Thing (IoT). This infrastructure provides energy optimization in linear sensor while preserving appropriate network delay. Figure 2 illustrates the basic energy-efficient linear sensor network applied in smart city application.

![Figure 2. Energy-Efficient Linear Sensor Network](image)

The communication channel of “IR-based wake-up receiver (IR-WuRx)” is implemented over an ordinary WiFi network for improvement of energy efficiency. In multihop communication for linear sensor network topology, the IR pipelined relay method is investigated to verify network delay for end-to-end signal transmission. The energy efficiency and well preserved constant network delay are observed by experimental results.

Moreno et al. [24] proposed an IoT enabled location-aware platform which addresses the issue of intelligent data accumulation and processing to optimize the energy by modifying the functioning of related indoor smart devices. The identity and location of the user is the key
aspect and essential component of this energy-efficient system which provides customized services and avoids useless power consumption.

Chithaluru et al. [25] proposed and implemented “I-AREOR” protocol for IoT enabled green smart city using energy-balanced clustering. For cluster head selection, this method examine proportional node distance, local sensor density and remaining energy of each node in WSN. Various energy factors are considered for selection of cluster head to enhance network lifetime and various impacting factor are applied to manage energy utilization. To forward data from node to cluster head, a dynamic threshold quantity is used in each round. Their outcomes illustrate that “I-AREOR” method enhances the number of rounds earlier to death of first sensor node.

Qureshi et al. [26] proposed “interference aware energy efficient transmission protocol (IEETP)” for smart city based healthcare applications using body sensor network (BSN). In this system, next forwarder sensor node is selected based on its residual remaining energy, location, distance and local density. “IEETP” is based on multihop protocol where data is forwarded from source node to the body node coordinator (BNC) of the network. For evaluation of routing parameters, a weighting factor technique is applied in the network, and the next forwarder node is decided based on those values. The “IEETP” protocol presents optimized energy utilization and low loss of packets as compared to other protocols by their experimental results.

3. Proposed System Model

In the smart city based wireless sensor network, the communication between receiver and transmitter nodes depends on the signal strength of electromagnetic wave. The data transmission usually consumes more energy as compared to sensing and processing. In modern smart city, the base station may be stationary or unmanned aerial vehicle (UAV) based for sensed data collection. The sensor node having higher residual energy will take the responsibility for data collection from other nodes and transmission to the base station. A sensor node sends $l$ bit data using transmission energy $E_{Tx}$ and receiver node consumes $E_{Rx}$ energy to receive that data at distance $d$, which can be represented as:

$$
E_{Tx}(l, d) = \begin{cases} 
  l \cdot E_{elec} + l \cdot \epsilon_{fs} \cdot d^2, & \text{if } d < d_0 \\
  l \cdot E_{elec} + l \cdot \epsilon_{amp} \cdot d^4, & \text{if } d \geq d_0
\end{cases}
$$

(1)

$$
E_{Rx}(l, d) = l \cdot E_{elec}
$$

(2)

where $\epsilon_{fs}$ is the permittivity of free space, $\epsilon_{amp}$ is permittivity using power amplifier losses, $E_{elec}$ is energy loss coefficient of sensor node to send and receive $l$ bit data, whereas $d_0$ is the threshold distance.

The set of sensor node in this system are $\{S_1, S_2, \ldots S_n\}$. The transmission power $E_{Tx}$ of sensor node completely depends on the residual energy $E_{res}$ of the sensor node, so the linear regression model is considered as the affiliation between residual energy $E_{res}$ (as independent variable) and transmission power $E_{Tx}$ (as dependent variable). The linear relationship residual energy $E_{res}$ and transmission power $E_{Tx}$ of sensor nodes is represented in Figure 3.

The system model can be represented in the mathematical form using linear regression. For total $n$ number of sensor nodes, the mean value for residual energy $E_{res}$ and transmission power...
Residual Energy \((\text{mAh})\)

| Transmission Power (J) |
|------------------------|
| 100  | 200  | 300  | 400  | 500  | 600  | 700  | 800  | 900  | 1000 | 1100 | 1200 |
| 3600 | 7200 | 10800| 14400| 18000| 21600| 25200| 28800|

Figure 3. Linear Regression Relationship of Residual Energy and Transmission Power of Sensor Node

\(E_{\text{Tx}}\) can be calculated as

\[
E_{\text{res}} = \frac{1}{n} \sum_{i=0}^{n} E_{\text{res}} \quad (3)
\]

\[
E_{\text{Tx}} = \frac{1}{n} \sum_{i=0}^{n} E_{\text{Tx}} \quad (4)
\]

The slope \(m\) for the best fit line is calculated as

\[
m = \frac{\sum_{i=1}^{n} (E_{\text{res}} i - \bar{E}_{\text{res}}) (E_{\text{Tx}} i - \bar{E}_{\text{Tx}})}{\sum_{i=1}^{n} (E_{\text{res}} i - \bar{E}_{\text{res}})^2} \quad (5)
\]

Finally the prediction model where transmission power can be predicted based on residual energy for selection of best sensor node to transmit data to base station is presented as

\[
E_{\text{Tx}} = m(\bar{E}_{\text{res}}) + c \quad (6)
\]

where \(c\) represents vertical intercept in this relationship as a constant.

In this proposed system, initially the residual energy and its corresponding transmission power is given to the linear regression model, since transmission power depends on the residual energy of the sensor node. The proposed system is illustrated in Figure 4, the previous values of residual energy and transmission power are given to linear regression model, then it generates a prediction model. Based on this model the transmission power of sensor node can be calculated for data transmission as higher residual node is best suitable for data transmission to the base station. This proposed system creates a balance network for higher energy efficiency in smart city.

4. Result Analysis

The random selection of sensor node for data transmission to the base station can reduce the network lifetime. The random prediction creates higher error rate for node selection to transmit
data. Figure 5 represents that the random data transmissions have higher error rate and linear regression based prediction transmissions have low error rate.

In the random data transmission, the number of node dead during transmission is higher, whereas during linear regression based transmission less number of node dead occurs as represented in Figure 6. The proposed linear regression based prediction model for sensor node selection significantly improves the network lifetime and reduces the error rate for node selection in smart city based wireless sensor network (WSN).

5. Conclusion and Future Work

Wireless sensor networks (WSNs) are the key component for smart city development. So, the energy efficiency is the central point for research in WSN. This paper presented an energy-efficient approach using linear regression based model for sensor node selection to collect and transmit data to base station. This proposed approach created an efficient method for wireless sensor network which performs far better as compared to random data transmission. The simulation results explain the efficiency of the model concerning prediction error for node selection and network lifetime.
The proposed system can be extended using other regression analytical model depend on various conditions. The other factors and parameter can be considered as extended or multiple independent variables to enhance this work. The linear regression analysis can be associated with other modern energy-efficient protocols for smart city based WSNs.

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