Essence of Scalability in Wireless Sensor Network for Smart City Applications

1Roopali Dogra, *2Shalli Rani, 3Bhisham Sharma, and 4Sandeep Verma
1,2Chitkara University Institute of Engineering and Technology, Chitkara University, Punjab, India
3Chitkara University School of Engineering and Technology, Chitkara University, Himachal Pradesh, India,
4Dr BR Ambedkar National Institute of Technology Jalandhar, India

*Shalli.rani@chitkara.edu.in

Abstract. Internet of Things (IoT) is the emerging research area. Along with many physical objects, Wireless Sensor Networks (WSNs) play an impeccable role in the smart city applications. It is learned from the retrospective study that the interaction between different types of objects, gathering of data from all the zones, their analyses etc., are very difficult to handle without energy conserving algorithms and protocols. Furthermore, applications of IoT specifically smart cities require a fault tolerant, scalable and reliable framework for real time processing of collected data. In this paper, we have proposed a cluster-based routing methodology which could be used at the sensing layer of smart city IoT. We select Cluster Head (CH) based on energy, distance, network energy and node density. The consideration of above parameters helps in acquiring the optimized performance of the protocol Zone-Stable Election Protocol (Z-SEP). We have performed simulations in MATLAB to emphasize the role of scalability of WSN in smart city application. We found that this protocol under performs when it is encountered for scalability.

Keywords: Internet of thing, Smart city, wireless sensor networks, WSN, MATLAB

1. Introduction
With the advancements in technology, the Internet of Things (IoT) has made it possible to develop and associate everything of traditional city with the sensing revolution and hence making it a smart city [1], [2].
Smart city projects have already issued many challenges in the Urban Living style. It is forecasted by the United Nation Population Fund (UNPF) that by Year 2030, approximately 59% of the world’s population will have smart environment [3]. For the healthy lifestyle and sustainable growth, some intelligent solutions are to be sought. However, the expansion of Information and Communications Technologies (ICT) and strength of internet can play a great role in seeking these solutions [4]. In the past decade, countless efforts have been made in the emerging area of IoT, where various devices can communicate with each other and can have inter-operable property [5].

These devices can range from cell phones and sensor nodes to the network enabled objects like Radio Frequency Identification (RFID), smart audio-visual etc., and can operate in global integration environment [6]. The emergence of smart cities has boosted the growth of IoT and has enhanced the quality of everyday life. New technologies are coming to the trend and new standards are being developed as the building block of applications.

As the size of data increases with many folds, it becomes necessary to gather, integrate, process and present the data derived from intelligent objects and merged with partaking sensing [7]. It requires many significant efforts to deal with the data which is derived from various perspectives and to handle the challenges of open and dynamic environments. One solution to these issues can be Public Sensing (PS) which services the large scale sensor network at very low cost by using the daily life sensor nodes and move-able devices where data can be shared with large number of users [8]. In the umbrella of IoT, PS will incorporate heterogeneous data generating systems which embeds Wireless Sensor Networks (WSNs), data warehouses, environmental monitoring devices etc. deployed in the smart cities [9]. Figure 1 shows the demonstration of IoT-based smart city [10].

To include any type of data from any source the term Sensor can be expanded which can be static or mobile (This term is used here to demonstrate the link between IoT and WSNs). It will be independent of the communication protocol or technology. A large scale distributed network will provide
diversified services to improve the quality of smart living [12]. Sensors are deployed in copious quality in buildings and on roads and are available on individuals, private and public vehicles [13]. Figure 2 shows the components of smart city.

Data gathering in energy efficient way in IoT environment exercises many strategies and pose several difficulties. Therefore, there is demand on novel technologies which will gather and analyze the real time data. To address this issue, a large WSN, with platform independent feature and generic IoT architecture is required which can aid in data processing, analytics, management and data processing [14]. With the advancements in new techniques, data is processed and gathered in real time which is converted into deliverable form. This enhances the decision making power of the people and helps in the implementation of smart city projects. Moreover, the heterogeneous data, gathered by the prevalent IoT, may be exploited to enhance the transparency and endorse the actions of government for the well-being of citizens.

Figure 2

1.1 Significant Contributions

The objective of this paper is to discuss the need of smart city, challenges and integration of sensor networks with IoT to implement the applications of smart city. In nutshell, the major contributions can be mentioned as follow:

a) We highlight the role of cluster-based routing scheme in smart city applications. To do so, we first discuss the various components and dependent factors with the smart city.

b) Thereafter, we do simulation analysis of proposed cluster-based routing protocol. We select CH based on energy, distance, node density and network energy.

c) Hence, we highlight the role of energy-efficient routing protocols for smart city applications.

The remaining paper is organized as follows. The related work is discussed in Section 2. Further, in Section 3, the proposed work is presented. Finally, in Section 4, the conclusion is discussed.

2. Related Work

Smart and Intelligent systems can bring a new change in the urban lifestyle [17] [18]. A lot of literature work suggests that some issues still need to be resolved for the proper implementation of smart city projects [19]. Authors have explained some issues related to smart cities in [20]. A cognitive management framework is proposed in which objects will dynamically interact with each other. They have implemented it in the virtual environment. Applications are spanned in a horizontal way and a scenario is created for the communication. They have proposed that self-re-configurable IoT can be achieved in smart cities. But they have not discussed the crucial importance of sensor nodes in the implementation of smart decisions. A new framework is proposed in [21] for service based applications. Data is shared with the help of cloud various data sources. An online heuristic for public data delivery is proposed and a utility function is introduced for data acquisition. Resource constraints in terms of delay, capacity and lifetime of data by service providers are considered in the utility function with the quality and trust issues of users. However, real-time data sharing problem and network lifetime are not considered in this proposal.

To realize the need of IoT in smart cities, a framework is presented in [22]. It has elaborated the urban information system which includes the sensory and networking support to the data and cloud integration for various services [6]. It is applied to the noise case study to demonstrate the new function for existing operations which can be modified for the improvement and delivery of vital city services. A comprehensive survey of the different protocols, technologies and architectures for IoT is presented in [23]. It has discussed the possible solutions and, guidelines for the Padova Smart City in collaboration with the municipality of the city. None of the above work, has discussed the essential need of WSN and its constraints which can increase the difficulties for IoT.
Moreover, already existing protocols for WSN are not suitable for IoT framework. Protocols like HCR, LEACH, HEED, TEEN, APTEEN, ERP, MODLEACH, etc. [16], require the optimization, so that they can be integrated with the frameworks as discussed above. In some of the recently reported studies, Alnawafa and Marghescu in [24] proposed an approach in which the network division is done into various levels. The nodes act according to their location and energy information in the network operation. Two routing strategies; static and dynamic have been proposed that decides for the route between the nodes. Simulation results have shown that the proposed techniques by the authors have outperformed in the context of various performance metrics. However, this algorithm suffered from the energy hole problem which consumes a lot of energy. Verma et al. [25] proposed MEEC that considered four sinks around the network. It eventually increased the cost factor for the network.

Behera et al. [26] proposed a protocol i.e., R-LEACH that used residual energy for the CH selection. It is an improved version of LEACH protocol. It considered initial energy, residual energy, and optimum CH values for selection of CHs. The drawback of this protocol is that it did not consider the distance factor for CH selection. Behera et al. [27] proposed i-SEP protocol that is the improvement of the SEP protocol. The traditional consideration of protocol makes it less competitive. The aforementioned protocols did not perform in the context of load balancing. The protocol Z-SEP divides the network into different zones wherein each zone has a CH that forwards the data to the sink. The protocol has performed exceptionally well in handling the energy balancing in the network. Hence, for the smart city application, it is necessary for a protocol to be scalable. We examine the scalability of Z-SEP in this work.

3. Proposed Framework

The proposed scheme in this paper focuses on the efficient routing for IoT framework which is responsible for gathering and transmitting the data in Z-SEP. This scheme is different in transmitting the data to the next level than traditional routing protocols. It performs the data delivery in the following manner:

a) IoT sensors are organized in a zone-based topology where interested sensors for some common event will get together and will cooperate with each other to transmit the data. Communication will be based on the inter/intra coordination and threshold energy.

b) Data will be transmitted in the multi-hop fashion through the virtual topology.

c) We have assumed the scenario of smart transportation where Humidity sensor, Temperature sensor, Motion sensor, Light sensor, etc. will be installed. This system is concerned about the safe transportation. The cohesive sensors are connected to the internet to permit the remote control of the transport vehicles. The activities of the sensors are related to each other. Temperature and humidity sensors will work in coordination. The motion sensor will affect the light sensor.

d) Our idea is to notify or establish the communication based on some triggered event. On the notification of some event, nodes are organized in virtual topology and data is transmitted from the interactive user to the attentive sensors.

e) The whole network is static in the sense that sink, and nodes are stationary for the entire network run.

f) The security aspects are not considered in the manuscript.

3.1 Radio energy model and proposed energy consumption model for Z-SEP
The energy consumption of nodes is decided by the radio energy model which is shown in Fig. 4. It decides the transmission and reception of $l$-bit message data. It is noted that it is the communication that energy consumes gigantically rather than the energy consumed in computation. Hence, we consider the communication energy in this work. The energy consumed in the transmission of data packets is given as:

$$E_{TX}(K, d) = \begin{cases} KE_{elec} + Kd^2E_f & \text{if } d < d_0 \\ KE_{elec} + Kd^4E_{mp} & \text{if } d \geq d_0 \end{cases}$$

Here, $E_{elec}$ denotes the energy expenditure per bit to run the circuit of transmitter/receiver. When threshold distance ($d_0$) is greater than distance ($d$) then free space ($E_f$) energy model is used otherwise, the multi path ($E_{mp}$) energy model is used. The threshold distance ($d_0$) can be computed as follow:

$$d_0 = \sqrt{\frac{E_f}{E_{mp}}}$$

For receiving of $K$-bit data ($E_{RX}$) the energy expended can be computed as follow:

$$E_{RX}(K) = K \times E_{elec}$$

The energy disburse during data aggregation can be computed as follow:

$$E_{da}(K) = p \times K \times E_{da}$$

Here, $p$ represents number of data packets and $E_{da}$ represents energy expended in data aggregation of 1-bit data.

Z-SEP exploits the heterogeneity of nodes while its network run. In our work, we consider two heterogeneous nodes; normal and advanced nodes. These nodes are represented by $N_{NORM}$ and $N_{ADVN}$ and are given eq. (5-6). The quantity of these high-energy nodes i.e., advanced and normal nodes are represented by $p_o$ and $p$, respectively.

$$N_{ADVN} = n \times \phi$$

$$N_{NORM} = n \times (1 - \phi)$$

The amount of energy in advanced nodes are $\phi$ times more to that of normal nodes. The symbols $\phi$ represents advanced node’s energy. The computation of total energy of the network represented by $E_T$ is done through the set of eq. (7-11). $E_{ADVN}$ and $E_{NORM}$ represent the energy of advanced, and normal nodes, respectively.

$$E_{ADVN} = E_0 \times (1 + \phi) \times n \times \phi$$

$$E_{NORM} = E_0 \times (1 - \phi) \times n$$

$$E_T = E_{ADVN} + E_{NORM}$$

$$E_T = E_0 \times (1 + \phi) \times n \times \phi + E_0 \times (1 - \phi) \times n$$

$$E_T = E_0 \times (1 + \phi) \times \phi \times n$$

Though, energy used by the CH and non-CH, which is represented by $E_{CH}$ and $E_{non,CH}$ during one
round can be calculated as:
\[
E_{\text{CIH}} = P \times E_{\text{elc}} \times \left( \frac{n}{k} - 1 \right) + P \times E_{\text{da}} \times \left( \frac{n}{k} \right) + P \times E_{\text{elc}} + P \times E_{\text{efs}} \times (d_{bs}) \times (d_{bs})
\] (12)
\[
E_{\text{non_CIH}} = P \times E_{\text{elc}} + P \times E_{\text{efs}} \times (d_{ch}) \times (d_{ch})
\] (13)

Where ‘n’ is the number of nodes present in the network, ‘k’ is number of clusters, and ‘d_{bs}’ represents the average gap from cluster head to sink and d_{ch} is the average gap between node to cluster head(CH).

The total energy consumed in the network, represented by \( E_{\text{total}} \) is:
\[
E_{\text{total}} = P \times (2 \times n \times E_{\text{elc}} + n \times E_{\text{da}} + (k \times d_{bs}^2 + n \times d_{ch}^2))
\] (14)

As this model assumes nodes are distributed randomly in network. so,
\[
d_{ch}^2 = \int \int ((a^2 + b^2) \times \rho(a,b)) \, da \, db = \frac{N^2}{2\pi k}
\] (15)
\[
d_{bs} = \int (a^2 + b^2) \times \frac{1}{A} = 0.765 \times \frac{N}{\pi}
\] (17)

When we calculate derivative of \( E_{\text{total}} \) tends to zero then we find optimal number of cluster denoted by \( K_{\text{best}} \) i.e.,
\[
k_{\text{best}} = \frac{\sqrt{n}}{2\pi k} \sqrt{\frac{E_{\text{efs}}}{E_{\text{mH}}}} \sqrt{\frac{N}{d_{bs}^2}}
\] (18)

The best probability of a node to become as cluster head, \( p_{\text{best}} \) can be calculated as follows:
\[
p_{\text{best}} = \frac{k_{\text{best}}}{n}
\] (19)
\[
T_{n,th} = \begin{cases} 
p_{\text{best}} \times (r \times \text{mod} - 1) \\
1 - p_{\text{best}} \times (r \times \text{mod} - 1) \\
0 & c_i \in C \\
\text{else} & 
\end{cases}
\] (20)

Where \( r \) is the current cycle, \( C \) is the set of currently available normal nodes that have not become CH with in the last \( p_{\text{best}} \) rounds of normal nodes. In eq. (21), \( N_d \) denotes the node density of \( i^{\text{th}} \) node, \( NE_i \) represents the network’s energy, \( E_{\text{advance}} \) represents the energy of advanced nodes. The symbols \( \phi \) and \( \theta \) denote the advanced nodes energy fraction and quantity fraction of advanced nodes, respectively.
\[
p_{\text{best}} = \begin{cases} 
p_{\text{norm}} \times N_d \times NE_i \\
p_{\text{advance}} \times D_{l-s} & c_i \text{ is normal node} \\
p_{\text{advance}} \times E_i \times N_d \times NE_i \times (1 + \phi \times \theta) \\
E_{\text{advance}} \times D_{l-s} & c_i \text{ is advanced node} 
\end{cases}
\] (21)

| Network Model                  | Values                          |
|--------------------------------|--------------------------------|
| Network Area Size              | 100 x 100 m² and 200 x 200 m² |
| Number of Nodes (N)            | 100, 200                        |
| Initial energy of nodes (in Joules) | 0.5                             |
### Table 1

| $(E_o)$ | Energy heterogeneity Node Type | 2-level; normal and advanced nodes |
|---------|-------------------------------|-----------------------------------|
| Energy fraction of advanced nodes($\phi$) | $\phi = 1$ |
| Advanced nodes fraction $(\varphi)$ | $\varphi = 0.1$ |
| Energy required for running transmitter and receiver $E_{elec}$ | 50nJ/bit |
| Threshold distance $(d_o)$ | 87m |
| For $d \leq d_o$, value of $E_{elec}$ | 10pJ/bit/m$^2$ |
| For $d > d_o$ value for $E_{mp}$ | 0.0013pJ/bit/m$^2$ |
| Data aggregation energy, $E_{da}$ | 5nJ/bit/signal |
| Packet size | 2000bits |

### 4. Results and Discussions

We have performed the simulation runs in the MATLAB. MATLAB is the high performance and efficient programming language for technical computing which provides the visualization, processing and programming at one platform only.

![Graph](image-url)

**Figure 5.** Alive nodes versus rounds for Case I and Case II for Z-SEP

Fuzzy logics, simulations, C language style, etc. programming can easily be done in it. There are many simulators like NS2, NS3, OMNET++ etc. which can be used for the WSN programming but in MATLAB a free style programming gives the programmer more control over the developed software.
Case I

Case II

Figures 6. Dead nodes versus rounds for Case I and Case II for Z-SEP

The simulation parameters are given in Table 1. We simulated the Z-SEP protocol proposed in [14]. We just changed the area from 100 square meters to 200 square meters and location of the sink is 100 by 100 by discussing two cases as shown in Figure 5, Figure 6 and Figure 7. We found that a protocol (Z-SEP) which was performing better than LEACH and SEP, has lost its efficiency as the nodes of Z-SEP deplete energy earlier than LEACH, which will also affect the throughput and network lifetime. It can be noticed from the Figures 5-7. Therefore, it is concluded that Z-SEP it not suitable for IoT. It needs to be optimized.

In these figures it is very clear that Z-SEP can perform better, if it is optimized. Throughput of Z-SEP much higher than LAECH and SEP which is required in smart city projects. But energy efficient communication is also a major constraint of integrated IoT-WSN. We discussed in the third section that, our proposed methodology will work in cooperative environment. With this proposed solution, we hope that we will achieve the balanced load on the nodes and hence the energy efficient communication with higher network throughput.

Smart city applications; require optimization of traditional routing protocols of WSN. In this paper, we propose the hierarchical communication (hierarchy of clusters), where intra and inter cluster communication is possible to transmit the data. We will try to reduce the communication distance of the nodes to conserve more energy and to enhance the network lifetime. Scalability is another important feature of internet of things for smart cities. For a large scale network, again a chain based communication is required to conserve energy.
5. Conclusion
In this paper, we have introduced the challenges faced by the smart cities. We have proposed a scheme, which can facilitate the integrated IoT-WSN. We have shown that some routing protocols which are working on the small areas, are not suitable for the large area. Smart city applications require that nodes should interact at the large scale network and they should be capable of communication for long time. We have given the example of Z-SEP, and have shown that in terms of energy, it does not perform well when its area is increased. But network throughput of Z-SEP is much better than LEACH and SEP. Change in the communication topology can improve it to use it in IoT. We recommend a chain based communication for energy conservation schemes for smart cities.

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