Building Efficient Multi-level Wireless Sensor Networks with Clustering

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Abstract. Wireless sensor networks will be responsible for the majority of the growth in smart building systems over the next decade. In resource constrained wireless sensor networks, it is very important to design the protocols with energy efficiency to prolong the lifetime of the sensor networks. Node clustering and data aggregation become popular since cluster-based sensor network can enhance the whole network throughput by aggregating the collected sensory information in each cluster. In such a network, the cluster head nodes play an important role in forwarding data originated from other common nodes to the sink. As a consequence, the cluster head nodes will have the problem of quick energy depletion upon multiple packets forwarding in high data load sensor networks. In this paper, we proposed a simple cluster-based linear network coding protocol in which random linear network coding is applied at cluster head nodes in order to minimize the number of forward packets to the sink. Simulation results are provided to show the efficacy of the proposed method in terms of the throughput and end-to-end delay.

Keywords: Wireless sensor network · Building · Clustering

1 Introduction

Availability of low-cost sensing and processing modules as well as recently developed efficient wireless communication protocols for building automation applications provide the basic enabling tools for the application domain of smart buildings. Smart building systems are becoming more and more vital due to the improvement they provide to the quality of life. One of the key components of a smart building system is a wireless sensor network (WSN), which provides the necessary information to the smart building system, allowing it to control and monitor the physical environment.

A WSN is formed by a large number of sensor nodes to monitor the objects of interest or environmental conditions such as sound, temperature, light intensity, humidity, pressure, motion and so on through wireless communications [1]. As the technology of WSNs matures, the scope of their applications has become more extensive, e.g., environmental monitoring, home automation, intelligent office, energy saving, intelligent transportation, health care, and security monitoring [2]. A major limitation of untethered nodes is finite battery capacity and memory and thus power efficient configuration of WSN has become a major design goal to improve the

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performance of the network. Due to the limited resources of sensor nodes, it is very important to design a routing protocol with energy efficiency to extend the lifetime of the WSN. Several solution techniques have been proposed to maximize the lifetime of battery-powered sensor nodes. Among the various techniques, it is well-known that cluster architecture enables better resource allocation and helps to improve power control.

In the clustered environment, the data gathered by the sensors are communicated to the base station (BS) through a hierarchy of cluster-head (CH) nodes [3]. With clustering in WSN, the randomly distributed sensor nodes are formed as many clusters and each sensor node has to transmit the collected data to its CH. After deployment, the CH is responsible for collecting data from its cluster member sensors, and those collected sensor data are aggregated and then forwarded to the BS via the sink. Thus, the CH plays an important role in aggregating and forwarding data sensed by other common nodes and as a consequence CH consumes more energy than the other member sensors. In addition, another limitation of the sensor node is the buffer size and it is also very important to efficiently utilize the limited buffer of the sensors. In this paper, we propose architecture of cluster-based WSN with the use of linear network coding at CH nodes to optimize the throughput and delay of high data load sensor networks.

The remaining of this paper is organized as follows. We first discuss the related works in Sect. 2. We then briefly present our proposed network architecture in Sect. 3. Simulation results and discussions are presented in Sect. 4. Finally, we conclude our paper and present our future work in Sect. 5.

2 Related Works

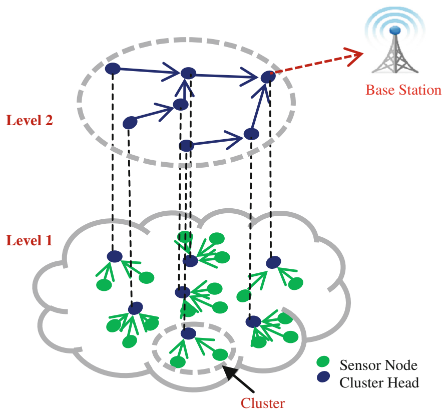
WSNs are event-based systems based on the collaboration of several micro-sensor nodes [4]. The high density of sensor nodes is vital for sensing, intrusion detection, and tracking applications. When an event is detected in the network, the aggregated collaborative report of the detecting nodes is delivered to the sink. Clustering mechanisms enable the sensor nodes to collect and aggregate data at nodes called CHs in each cluster. However, due to the high data load nature of monitoring sensor networks, the cluster head nodes will suffer from the problem of packet overwhelming over the time [5].

Since the packet transmission is the most power consuming action for sensor nodes and the network coding technique reduces the number of packet transmissions, network coding becomes useful to reduce the energy consumption in WSN. Network coding technique [6] allows cluster head node to produce the linear combination of the received packets from its cluster member nodes before sending the data to the sink. The operations are computed in the finite field and thus the result of the operation is also of the same length. The original packets can be recovered at the sink by solving the set of linear equations just after receiving the required number of linearly independent packets [7, 8].

The AODV Routing Protocol [9] uses an on-demand approach for finding routes, that is, a route is established only when it is required by a source node for transmitting data packets. AODV is suitable for dynamic wireless networks where nodes can enter and leave the network at will. To find a route to a particular destination node, the source node broadcasts a RREQ to its immediate neighbors. If one of these neighbors has a route to the destination, then it replies back with a RREP. Otherwise the neighbors in turn rebroadcast the request. This continues until the RREQ hits the final destination or a node with a route to the destination. At that point a chain of RREP messages is sent back and the original source node finally has a route to the destination.

3 Proposed Method

In this section, we will illustrate the network model of our study. We consider a simple cluster-based monitoring WSN where hundreds of sensor nodes generate the readings on every unit time and those sensory data are sent to the sink via CH. The network architecture of our proposed cluster-based linear network coding for WSN is illustrated in Fig. 1(a). As it can be seen in the figure, we logically consider the network as 2-level network. In level-1, the whole network is broken into set of clusters and member nodes send data to associated CH. In level-2, data communication is carrying out only among CHs in order to forward data to BS.



1. Each node is assigned a unique ID number.
2. The nodes broadcast the msg which contains its own ID (M_{id}).
3. **for** each received msg **do**
   Compare the node id with its own ID.
   if ID > M_{id} **then**
   Transmit $M_{CH\text{-}advertise}$
   end if
   end for
4. Listen $M_{CH\text{-}advertise}$ for T_w.
5. **if** no. ($M_{CH\text{-}advertise}$) = 1 **then**
   Update CH
   Transmit $M_{CH\text{-}associate}$ to CH
   end if
6. **if** no. ($M_{CH\text{-}advertise}$) > 1 **then**
   Update CH with highest RSSI
   Transmit $M_{CH\text{-}associate}$ to CH
   end if
7. **if** no. ($M_{CH\text{-}advertise}$) = 0 **then**
   Declare itself as CH
   end if

Fig. 1. (a) Architecture of proposed protocol (b) Algorithm for cluster forming.

Our proposed system can be mainly classified into two phases: (1) Cluster forming phase and (2) Data collection phase.

(1) Cluster Forming Phase: After all nodes are deployed, clusters are formed according to the algorithm shown in Fig. 1(b). In our algorithm, CH nodes are chosen based on the highest node ID (HID) and the received signal strength (RSSI). We assume that each sensor node has its own ID. In the beginning of the clustering phase, the nodes broadcast the message which contains its own ID. Due to the broadcast nature of the sensor networks, all the nodes in its communication range will receive that message. For each received message, the node will compare the embedded ID with its own ID.

If a node found that its own ID is greater than the entire received ID, it will broadcast the cluster head advertisement message ($M_{CH\_advertise}$). Entire nodes in the network will listen to the cluster head advertisement for the unit time T_w. After time T_w, if a node receives only one cluster head advertisement message, it means $no.(M_{CH\_advertise}) = 1$, it joins in that cluster and sends cluster head associate message ($M_{CH\_associate}$) back to that CH node then it updates its associate cluster head node. For the nodes who received more than one cluster head advertisement message, it means $no.(M_{CH\_advertise}) > 1$, sensor node decides which cluster to join based on the received signals strength. After choosing the cluster head, it sends cluster head associate message ($M_{CH\_associate}$) back to that CH node then it updates its associate cluster head node. For the nodes who did not receive any cluster head advertisement message in T_w, it means $no.(M_{CH\_advertise}) = 0$, it advertises itself as cluster head and form an isolated cluster. After joining cluster, sensor nodes send their data only to the associated CH node. In our cluster forming phase, we ensure that every node in the same cluster is in one-hop distance.

(2) Data Collection Phase: In the data collection phase, each node in the cluster sends its own packet to the associated CH. Only CH node performs network coding upon the packets in its own cluster. In here, we adopt the simple random liner network coding where CH node encodes *N*-packets in its buffer as one encoded packet and broadcasts the encoded packets only. The use of network coding has several benefits: reduce the transmission energy and enhance the network throughput.

Upon receiving n originated packets ($M^1, M^2, \ldots, M^n$) from its member nodes, the sequence of coefficients ($g_1, g_2, \ldots, g_n$) are chosen uniformly at random over the finite field f_2s. Then the associated CH node generates the encoded packet *P* by this equation:

$$P = \sum_{i=0}^{n} g_i M^i$$

Intermediate CH node acts as a relay in order to help the packets successfully arrive to the sink. Upon receiving the *n*-linearly independent encoded packets, the original packets can be decoded by the linear equation at the sink.

4 Simulation Results

4.1 Simulation Setting

We perform computer simulation using NS-2, a standard tool in sensor network simulation. The detail parameter setting for the simulations is shown in Table 1. In our simulation, we assume sensor nodes are stationary after deployment. All nodes in the network are homogeneous and energy constrained. The location of the sink node fix and far from the sensor network and the data sensed by the sensors can be reached to the sink node via CH nodes. We use CBR (constant bit rate) as traffic source and numbers of sources are 20, 40, 60, 80 and 100 separately.

Table 1. Simulation parameters

Parameters description	Values
Simulation area (m)	100 × 100
Network size (nodes)	100
Data packet size	512 Bytes
Transmission range (Sensors)	15 m
Transmission range (CH)	30 m
Simulation time (s)	500

4.2 Simulation Results

In order to evaluate the performance of our proposed protocol, we computed the packet delivery ratio and end-to-end delay with a period of 500 s under the proposed protocol and compared our proposed scheme with the standard routing protocol, AODV [9].

In Fig. 2, the first row shows the simulation results of packet delivery rate on different number of source nodes. This measurement was done assuming each sensor node in the network has fixed buffer size of 10. As we can see from the figures, the packet delivery ratio of our proposed method is higher than AODV in various number of source nodes. Although the performance is not very significant in low packet rate (1 Pkt/s), we can see the significant results in packet rate of 5 Pkt/s and 10 Pkt/s.

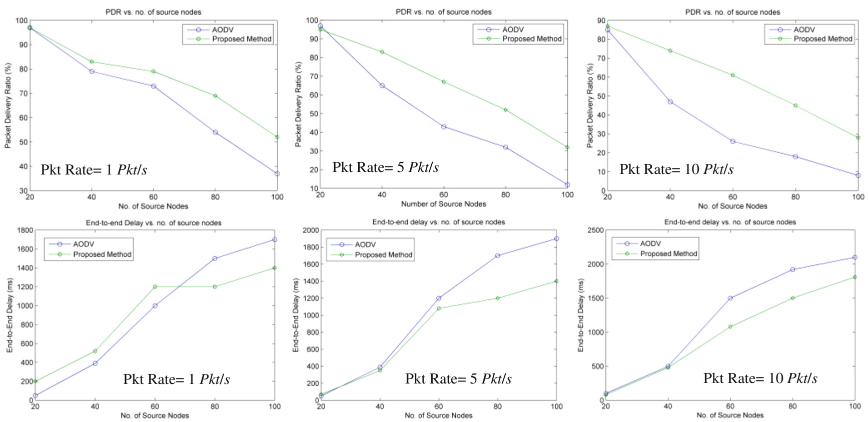


Fig. 2. Simulation results for PDR and end-to-end delay with various no. of source nodes.

We then plot the end-to-end delay as a function of the number of source nodes. We compare the average delay between our proposed protocol and AODV during the simulation time. With low packet rate which is 1 Pkt/s, our proposed protocol has more delay than AODV for the number of sources less than 60. This is because the CH node keeps the data packet until it receives enough packets to encode. However, when load becomes heavy which is greater than 60 sources, the performance of our proposed protocol becomes better.

In last two figures, even though the performance of our proposed protocol and AODV is not much different for sources less than 40, it is obvious to see that our proposed protocol outperform AODV for the heavy load which is sources greater than 60. From the results, we conclude that our proposed protocol is able to optimize the packet delivery ratio and end-to-end delay for the heavy load sensor networks.

5 Conclusion and Future Work

In this paper, a cluster-based network coding architecture for WSN was introduced and discussed. The basis of our protocol is using linear network coding only at the CH nodes in order to increase the throughput of the whole sensor network. Since only CH nodes perform data encoding and take responsibility to send the data to the sink node, it causes energy saving of member sensor nodes. Simulation results show that our proposed scheme outperform AODV in terms of PDR and end-to-end delay. In the future, we will research on the energy consumption and lifetime of the network.

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