Network Reconfiguration for Energy Efficient Clustering of Wireless Sensor Networks

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Abstract: This paper presents an autonomic network reconfiguration for energy efficient clustering of wireless sensor networks. Due to the main constraint of sensor nodes is their very low finite battery enery, which limits the lifetime and the quality of the network. For this reason, the protocols running on sensor networks must consume the resources of the nodes efficiently in order to achieve a longer network lifetime. Our approach is to reorganize the cluster head node by setting the mininum cluster head node remaining energy. If problem happens, cluster head will change to be a new node. This network reconfiguration will help to increase prolonging the node average working time and improving the network load balance.
Keywords: Reconfiguration, Wireless Sensor Networks

1. Introduction

A typical wireless sensor network (WSN) consists of a large number of small-sized battery-powered sensor nodes that integrate sensing, computing, and communication capabilities. One of the interested research topics in WSN is the design of energy efficient protocols optimized for the constraints of sensor nodes and for the requirements of the data dissemination in the network.

The topology of wireless sensor network is simply the way network architectures are arranged. Three of the most common wireless topologies for wireless sensor network applications are star, mesh and cluster-tree [1]. Star topology is a point-to-point of line of sight architecture where communicate directly with a base station. Star topologies potentially use the least amount of power of the three architectures because of the simple, direct wireless connections. But the distance of the data can be transmitted from the wireless sensor node to the basestation is limited to a range. For mesh topology, the sensor nodes in a mesh topology can also communicate with other nodes in the network (point-to-multipoint) using a capability called multi-hopping. The advantages of mesh over star topology includes a longer range distance and a decrease in loss of data or transmission. A cluster-tree topology is a hybrid where wireless sensor nodes in a star topology are clustered around cluster-head that communicate with each other and the base station in a mesh topology. This blends the advantage of both topologies is potentially low power consumption of the star portions of the cluster-tree, and extended range and fault tolerance of the mesh portions.

In this paper we focus on mechanisms for creation and reconfiguration of cluster-tree sensor networks based on IEEE 802.15.4 and Zigbee standards. Our main contributions are the proposed novel simple and energy efficient autonomic reconfiguration algorithms, handling the reorganization of a cluster-tree.

This paper is organized as follows. Section 2 highlights the creation of cluster-tree reconfiguration. Section 3 purposes the new algorithm for network reconfiguration of cluster-tree and describes methodology of network reconfiguration. Section 4 provides simulation results. Finally, section 5 concludes the paper and offer directions for further studies.

2. Cluster Tree Reconfiguration

According to the IEEE 802.15.4, the process of cluster-tree formation as shown in the Figure 1 starts when sensor node which has a capability to be a potential cluster head decides decides to start a new network. It advertises this decision and starts processing join-requests from other nodes. This cluster head selects a channel and a Network ID and starts distributing addresses. Its common assumption is that a network is static during the initial configuration phase. An initial cluster-tree configuration ends when either all nodes wanting to join a network get the corresponding addresses. After this initial phase a network enters a implement phase in which the network has to work as its duty.

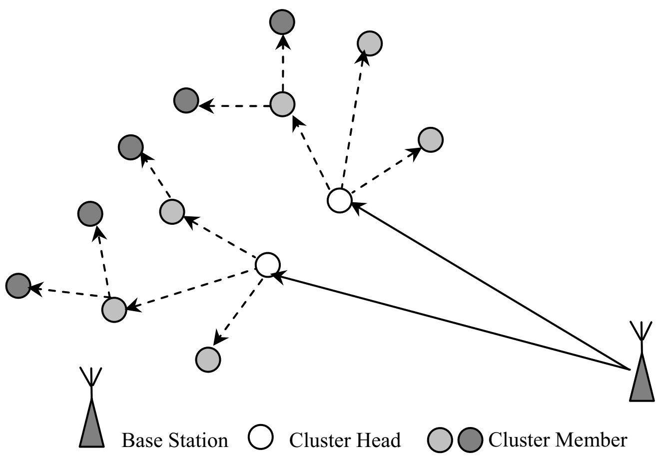

Figure 1: Cluster-tree Structure

Reconfiguration deals with the potential inefficiency of the cluster-tree addressing and routing due to the organic growth of a cluster-tree as devices are added to or removed from the network. The cluster-tree addressing scheme divides the address space in contiguous intervals and assigns them to the tree branches. In this case, reconfiguration may be considered as a necessary autonomic process.

Depending on which node in the network start the reconfiguration and how extensive the reconfiguration is we classify reconfiguration strategies within four groups [2]. First of all is the cluster head switch. The current cluster head triggers reconfiguration by selecting and activating a new cluster head. Second, it is to change the maximal number of children per node. The current coordinator propagates a new value for the maximum number of children per node to each node in a tree and rebuilds the tree. Next, it is splitting or merging cluster trees. A node detecting a problem such as the exhaustion of cluster member node takes a role of an additional coordinator and creates its own tree without changing the rest of the structure of the current cluster. Both trees need to be interconnected. In case of small clusters it would be also interesting to merge these into a single cluster. Finally, it is handover of children nodes. A node detecting a problem asks one or some children nodes if they can connect to a different parent node or cluster. If possible a child node releases the connection with the parent node and connects to another, more suitable one.

The first group of reconfiguration offers possibilities to reconfigure and optimize the cluster tree based on trigger condition. In our work we focus on this kind of reconfiguration due to energy consumption aspects in wireless sensor networks. We propose reconfiguring cluster-head [3] algorithms which can change automatically the network due to maintain life-time of energy efficiently.

3. Methodology

This purpose of this research is to design a self-configuring algorithm for wireless sensor network. The objective of the self-configuring algorithm is to handle energy efficient in cluster-tree sensor network when battery of cluster head is exhausted. Clusterhead remain energy will decrease rapidly because it will use for data aggregation, compression and processing including energy consumption of cluster head to transmit data within the radio communication range of a base station. Self-reconfiguring algorithm will manage new clustering, cluster head should be change to be other node for saving entire energy of sensor network. Reconfiguration based on cluster head switch has following algorithm.

1. Select clusterhead having high remain energy and nearest position of basestation by setting the minimum remain energy.
2. Create non-overlapping cluster as shown in figure 2a.
3. Trigger condition is the minimum remain energy could be set in cluster head node. If a conditon is satisfied, a cluster head will send data acquistion requests to base station for network reconfiguration.
4. Switch cluster head to be new node which is nearest the base station except the current cluster head and highest remain energy of cluster as shown in figure 2b. Cluster member node in level 1 will also be reconfigured.
5. The old cluster head becomes normal sensor node which can make harvesting energy or changing new battery for preparing to be cluster head again.

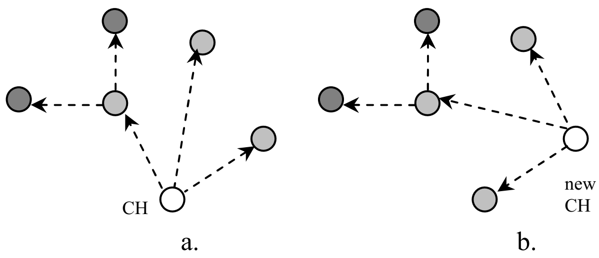

Figure 2: Cluster head switch scheme

3.1 Experiment system

We set up a test platform using Tmote node and Telos platform by Moteiv Corporation. First, we set up cluster node and generate function as normal sensor node. We can monitor the ranges of humidity, light and temperature values. When cluster head node is in the condition of state switching which is voltage value less than threshold, node will send data to base station. Tmote use the range of voltage in 2.1 - 3.6 V_{DC} and not less than 2.7 V_{DC} for programming on microcontroller [4]. Finally, we send scripts to all of node and perform the process of reconfiguration new cluster head as methodology. We can compute voltage formula as shown below:

$$Voltage = (data/4096)*3 \qquad (1)$$

The paradigms of formula can be explained in the message format in next section. For example of this formula, data is equal to F33. It was converted from hexa number (F33) to deca number (3891). Voltage can calculate to be 2.85 V_{DC}.

3.2 Message format

We use message_t of TinyOS 2.x to communicate in standard data packet for data transmitting between sensor nodes in wireless network. Message_t consists of 4 parts can be represented as:

- *Header* (length is 11 bytes) - it is parameter to assign the address of sensor node and the length of transmission data.
- *Data* (length is 29 bytes) - it contains data as user desired which depends on size of packet for example temperature or humidity value
- *Footer* - this field used for link layer check performing of Maximum Transfer Unit (MTU) of packet size. It will have or not have up to size more or less
- *Metadata* (length is 7 bytes) - this field is for keeping data such as Received Signal Strength Indicator (RSSI) etc.

Implementation of wireless sensor network, message_t can classify into 2 packets which are CC2420 and serial as shown in Figure 3. Both packets are different in header and serial packet does not have metadata. CC2420 packet is used for transmitting data between sensor nodes via RF signal. Serial packet is used for communication between computer such as base station and sensor node via UART (Universal Asynchronous Receiver/Transmitter)

```
              11 bytes       TOSH_DATA_LENGTH       7bytes
            +-----------+------------------------+--------+
message_t   |  header   |          data          |  meta  |
            +-----------+------------------------+--------+

            +-----------+------------+           +--------+
CC2420      |  header   |    data    |           |  meta  |
            +-----------+------------+           +--------+

                  +-----+------------+
Serial            | hdr |    data    |
                  +-----+------------+
```

Figure 3: Layout of message_t, a CC2420 packet, and a serial packet on the Telos platform [5]

In this case, we are interested both in CC2420 and serial packet which involve with network reconfiguration. TABLE I lists all the fields of header of CC2420 packet. We design the network reconfiguration message in header and data of CC2420 packet.

TABLE I
Header of CC2420 packet

Field	Definition
length	data length (unit is byte)
fct	frame control field for checking acknowledge of each package
dsn	data sequence number
destpan	destination PAN ID
dest	destination address of sensor node
src	source address of sensor node
type	packet type of data

TABLE II lists all the fields of metadata of CC2420 packet. We design for the setting the minimum remain energy message in metadata of CC2420 packet. The threshold of minimum energy can calculate and set up in sensor node with equation (1).

TABLE II
Metadata of CC2420 packet

Field	Definition
tx_power	enery value of each sensor node for sending data
rssi	received signal strength indicator
lqi	link quality indicator
crc	cyclic redundancy check for data correctness
ack	acknowledge for each package
time	time stamp for each package
rx_interval	the interval time of receiving data for each node

TABLE III lists all the fields of header of serial packet. We design the network reconfiguration message in header and data of serial packet.

TABLE III
Header of serial packet

Field	Definition
dest	destination address of sensor node
src	source address of sensor node
length	data length (unit is byte)
groupID	group ID of data packet
type	packet type of data

4. Simulation Results

We used the implementation of the Zigbee cluster-tree addressing scheme in the simulator and evaluated the optimized reconfiguration schemes as described in section 3. We evaluated from two aspects: the average end-to-end delay and the energy consumption of the entire network. The average end-to-end delay refers to the average time spent when a piece of data message is transmitted from base station to all of cluster member nodes. The entire network remaining energy can indicate the lifetime of the sensor network.

4.1 Goals and Metrics

Our goals in evaluating network reconfiguration for energy efficient clustering were three-fold: first, in order to validate some of the assumptions made during design of the scheme; perform analysis and simulations; and conduct comparative performance evaluation of the system with and without this reconfiguration; second, to understand the energy comsumption and delivery rate improvements that can be obtained by using this reconfiguration; finally, to study the sensitivity of network reconfiguration performance to the choice of parameters.

We choose two metrics to analyze the performance of network reconfiguration for energy efficient clustering: *Energy Consumption* is the ratio of the energy consumed by the Active case to the energy consumed by the network reconfiguration for energy-efficient clustering case. This metric defines the amount of energy savings and network lifetime we gain by using the network reconfiguration algorithm. *End-to-End Delivery Rate* is the ratio of the number of distinct packets received by destination to the number originally sent by the source. It provides and idea of the quality of the paths in the network and the effective multihop bandwidth.

Table IV: Simulation parameters

Simulation runs	2000
Simulation duration	40s
Simulation area size	1000x1000m
Communication range	10m
Number of nodes	90
Placement of nodes	Randomly by uniform distribution in the simulation area
Maximum number of child nodes per parent	3
Maximum tree depth	2

4.2 Energy Consumption

Since the active power consumption of the transceiver in a wireless sensor network node is much greater than its standby power consumption, the node must operate its transceiver in low duty cycle mode to get low average power consumption [8].

The approach taken in this work of performing switch of clusterhead to new clusterhead is compared to clustering approach in existing clustering schemes. The performance metrics is the mean clusterhead switch energy. The enery model is linear energy. The performance is measured for multi-hop clustering. In the following graph, the simulation experiment for sensor network of sizes 15, 45, 90 nodes reveals that clusterhead swich consumes 25%-30% less in normal clustering.

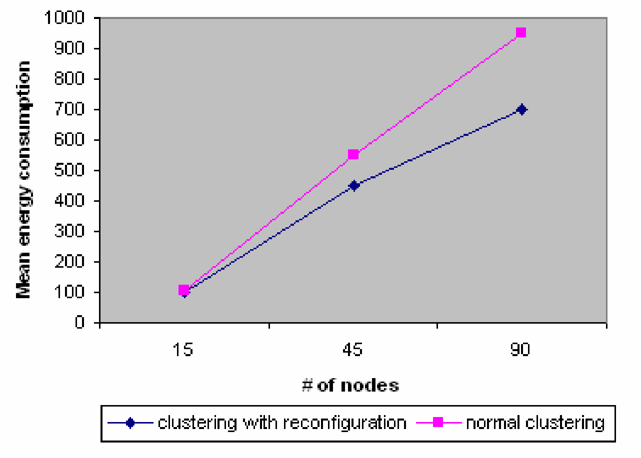

Figure 4: Mean energy consumption for normal clustering and clustering with reconfiguration

4.3 Delivery Rate

To understand the relationship between expected packet delivery and density of nodes, we first consider the transmission rate of connected nodes that its value is similar in each RF Power with sending and receiving data as shown in Figure 5. Therefore the RF Power is not necessary for evaluating the delivery rate. Assume that the switch of clusterhead can not change the transmission range which cover existing cluster member.

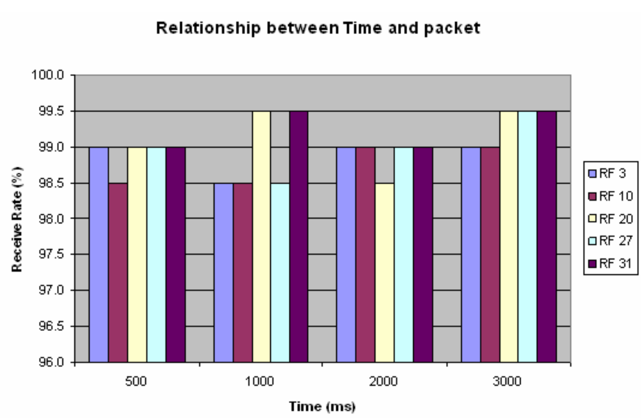

Figure 4: transmission data packet in different time for each RF Power

The next performance metrics is the end-to-end delivery rate. The performance is measured for multi-hop clustering. In the following graph, the simulation experiment for sensor network of sizes 15, 45, 90 nodes reveals that the end-to-end delivery rate of clusterhead swich is a few better the normal clustering

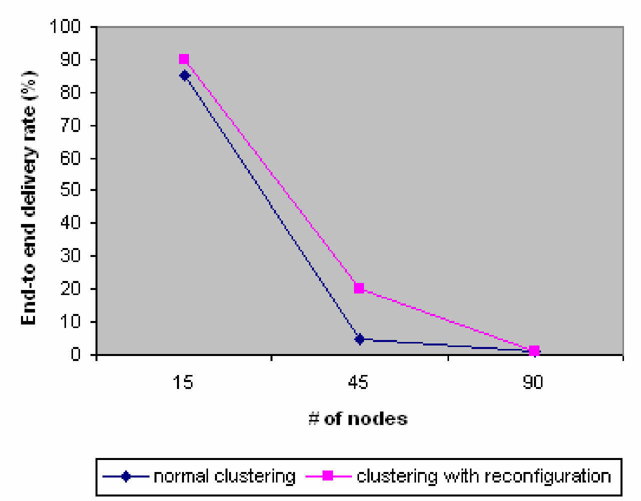

Figure 6: End-to-end delivery rate for normal clustering and clustering with reconfiguration

5. Conclustion

In this paper, we described the design, implementation, simulation of network reconfiguration for energy-efficient clustering of wireless sensor networks. There are many lessons we can learn from this paper. First, our network reconfiguration has potential for significant reduction of packet loss and increase in energy efficiency. Second, this algorithms was responsive and stable under some conditions.

In the future, we will find techniques to improve the performance of network reconfiguration for energy-efficient clustering of wireless sensor networks. We will investigate the use of load balancing techinques to distribute the energy load of clustering.

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