HOURGLASS Protocol with Two Base Stations for Smart Home Sensor Networks

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Abstract: — Smart Home is getting popular. An essential element of smart home is sensor network to convey environment information to the control station. There have been many communication protocols for this sensor network. One problem of previous protocols is unbalanced energy consumption among sensor nodes. Even though they tried to overcome energy unbalanced consumption, they could not solve this problem satisfactorily yet. In this paper, we find that basic reason for this unbalanced energy consumption is that there is normally one base node. Because of this architectural problem, the nodes around this sink node lose their energy more easily relative to other nodes. So, we propose the sensor network architecture with 2 base stations, and its corresponding communication protocol.

Key-Words: — Sensor Network, Communication Protocol, energy consumption, Smart Home, network lifetime.

1 Introduction

As ubiquitous computing is getting mature, it penetrates deeply into smart home environment. A smart home equips itself with many sensors to sense environment information. From this sensed information, it controls various devices to make better living condition autonomously. It has generated both a technology push as well as a user demand. Wireless sensor network (WSN) is the fundamental infrastructure of such environments. The recent extraordinary progress of sensor technologies makes it possible to build the micro sensors more powerful in communication, data processing and storage capacities with low cost and small size. However, they still have some restrictions in energy capacity.

Various communication protocols such as [1], [2], [3], [4], [5] and [6] have been proposed for WSNs in order to prolong network lifetime and enhance data quality. The SPIN family of protocols in [1] and [2] utilizes meta-data negotiations before any data is transmitted to assure that there is no redundant data sent throughout the network. Thus, it can save the network energy and bandwidth. In Directed Diffusion [3], C. Intanagonwiwat, et. al. proposed an approach using in-network data aggregation techniques to combine the data coming from different sources in order to minimize the number of transmissions. Following other approach, Heinzelman, et. al. [4] introduced LEACH, a hierarchical clustering protocol. In LEACH, the cluster head (CH) nodes compress data arriving from nodes that belong to the respective cluster, and send an aggregated packet to the sink in order to reduce the amount of information that must be transmitted to the sink. Similarly to LEACH, TEEN [5] and APTEEN [6] also utilize hierarchical clustering algorithms but with some enhancements. Cluster head sensors in TEEN and APTEEN send their members a hard threshold and a soft threshold to reduce the number of transmissions by allowing the nodes to transmit only when the sensed attribute satisfies such thresholds. These approaches, however, mostly could not maintain the balance of energy dissipation among the sensor nodes. Whether we want it or not, there are still some sensors which work harder and consume power much more than the others. For examples, some nodes near the sink need to transmit data for the nodes at further areas, or the cluster head nodes or leader nodes in hierarchical clustering protocols need to aggregate data coming from other nodes, and then send the final compressed packet to the sink. Such sensors may die very soon while others are still alive with high residual energy, and thus network performance and lifetime may be still low. Furthermore, a wireless sensor network protocol would rather be application specific. Nowadays there is still no prevalent protocol for smart home environment yet. It means that this area is a highly potential research field. The protocols for home environment have some inherent characteristics, with some particular requirements.

In this paper, we shall therefore propose a novel wireless sensor network (WSN) protocol, called HOURGLASS, which is a highly balanced energy dissipation protocol appropriate to home environment. The key idea in HOURGLASS is to uniform energy dissipation in both horizontal and vertical axes based on two base stations (BSs) topology, thus maximizing the network lifetime. Moreover, our approach also adopts the data aggregation and threshold techniques like the above approaches, but they are improved in order to work better with the home environment.

The rest of this paper is organized as follows. Section 2 describes briefly major reasons for energy consumption in wireless sensor network, and points out that unbalanced energy consumption is caused by one sink node. In section 3, we present our new innovative protocol HOURGLASS. We compare our model with other models in section 4. Finally, section 5 concludes the paper with a summary of our contributions and points out open research problems.

2 Major Reasons for Energy Consumption in Wireless Sensor Networks

In this section we intend to address some problems which frequently affect the lifetime of sensor network. First of all, the energy of recent sensor nodes is still restricted whereas their processing and storage capacities have been increased many times. This problem certainly influences the lifetime of the overall network. Secondly, we encounter the problem of transmitting data from each sensor node. Such transmitting consumes much more energy than sensing, processing and storing data. If a sensor network has to transmit data too frequently, its energy might be drained rapidly. Similarly, when flooding techniques or broadcasting messages are overused, they would cause network congestion. That problem could also shorten the network lifetime. Thirdly, data collected by many sensors in WSNs is typically based on common phenomena, especially in overlapped sensing areas; hence there is a high probability that this data has some redundancy. Furthermore, there are usually some data values which could be unnecessary for some applications. Transmitting such redundant or unnecessary data would consume the network energy irrationally. For examples, if the thermal application prefers to get the temperature greater than 50^{o}C only in order to raise a fire alarm, then sending the value 23^{o}C from every thermal sensor to the sink would waste the network energy. Finally, because the number of transmissions is different from each sensor, some sensors would be died sooner than the others. Thus, the network lifetime would be affected.

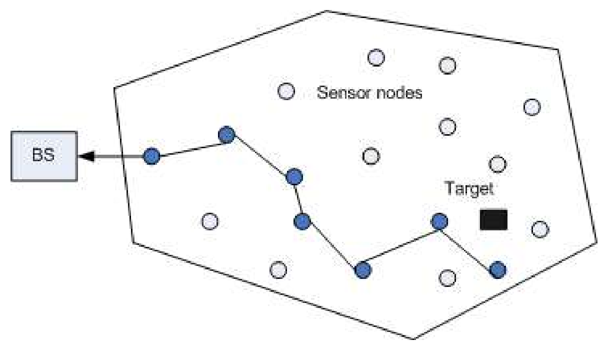

Fig.1: One-base-station topology

Besides all of the above, there is still one more design problem which could influence significantly the network lifetime. Most previous protocols use one-base-station topology. In this topology, sensor nodes are usually scattered in a target field. They collect and route the data back to a particular external BS through other nodes, as in the Fig.1. The sensor nodes near the BS, therefore, would specifically have more pressure than the other nodes which are located further from the BS because they might transmit data to the BS not only for their own, but also for the further ones. Such sensor nodes would consume their energy much faster than the others. Some protocols such as LEACH, TEEN and APTEEN utilize a clustering technique to solve this problem. Data is transmitted inside each local cluster first. Then the cluster head nodes compress such incoming data, and send it to the BS. Thus, it might reduce the amount of information that must be transmitted to the BS. In addition, the cluster head role is rotated randomly on few sensor nodes to keep some certain nodes from draining too much energy for this role. However, the idea of dynamic clustering brings extra overhead, e.g. head maintenances, head changes, new clusters' advertisements, cluster collisions etc.

3 HOURGLASS protocol details

3.1 Two Base Stations model

Our novel design idea is sharing the roles and responsibilities on every sensor equivalently. The sensor node which works hard will periodically change its phase to work lightly next turn, and conversely. Moreover, we try to avoid transmitting data to the same sensor node for a long time to extend the lifetime of sensor network. Before sending data to the BS, each sensor node will choose its next hop based on the number of use counts of this hop. Such hop with the smallest counts would be chosen as a next hop.

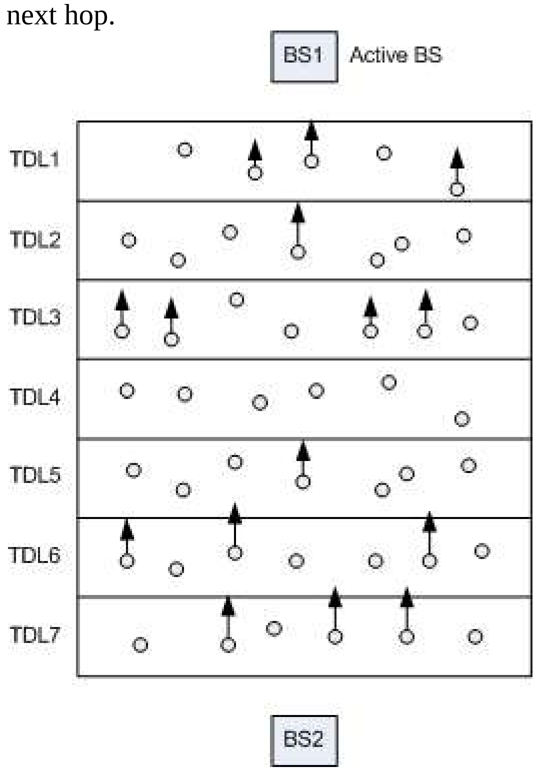

Fig.2: Two-base-stations model with active BS1

We propose a two-base-stations model as Fig.2 and Fig.3. Sensor nodes are freely scattered in a smart house. Then we put two base stations at each end of the sensor field so that the sensor nodes should be considered to be placed in the range of two BSs: BS1, BS2. We consider BS1 to be at top, and BS2 at the bottom of the network. The sensor nodes are classified into levels. There are two types of level: Top-Down Level (TDL), which is numbered increasingly from BS1 toward BS2 (starting from 1), and Bottom-Up Level (BUL), which is numbered increasingly from BS2 toward BS1 (starting from 1) as shown Fig.2 and Fig.3. A TDL defines a number of hops from the sensor nodes to BS1. Similarly, a BUL defines a number of hops from the sensor nodes to BS2. Owing to the communication with 2 BSs, each sensor node should have both a TDL and a BUL. The sum of such two levels, TDL and BUL, should be equal to the total number of levels N in one direction (top-down or bottom-up) plus 1 as given by:

$$TDL + BUL = N + 1$$

At first, BS1 works as an active BS (ABS). Every sensor node should transmit the collected data to this active BS in the bottom-up direction as in Fig.2. After a specific time, BS1 is deactivated and BS2 is activated. Then every sensor node should change the transmitting direction to the new ABS, top-down direction as in Fig.3. It continues working like this periodically. In the first turn, the sensor nodes which have TDL 1 should be the hardest ones. However, they will be the lightest ones in the next turn.

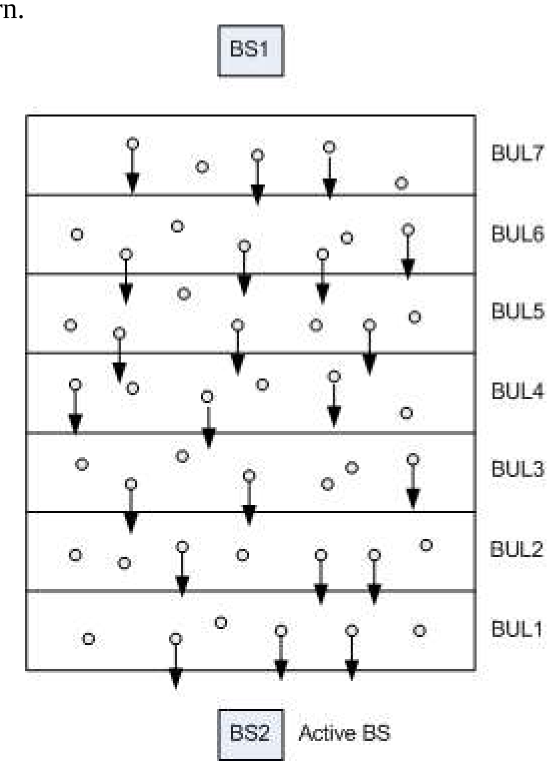

Fig.3: Two-base-stations model with active BS2

Besides indicating the number of hops to the BS, a level might also infer a transmission rate of the sensor nodes in this level. A low level sensor node should have a higher transmission rate than a high level sensor node. The sums of TDLl and BULl of every sensor nodes are equal to each other with value of N + 1. Hence, any 2 sensors in different levels but in the same routing chain in Fig.4 should be intended to have similar transmission rate, and consequently consume mostly the same amount of energy. In other words, energy would be dissipated almost equally among all nodes in vertical axis. The picture of this transmission method is similar to an hourglass' working method. That is why we name our protocol as HOURGLASS.

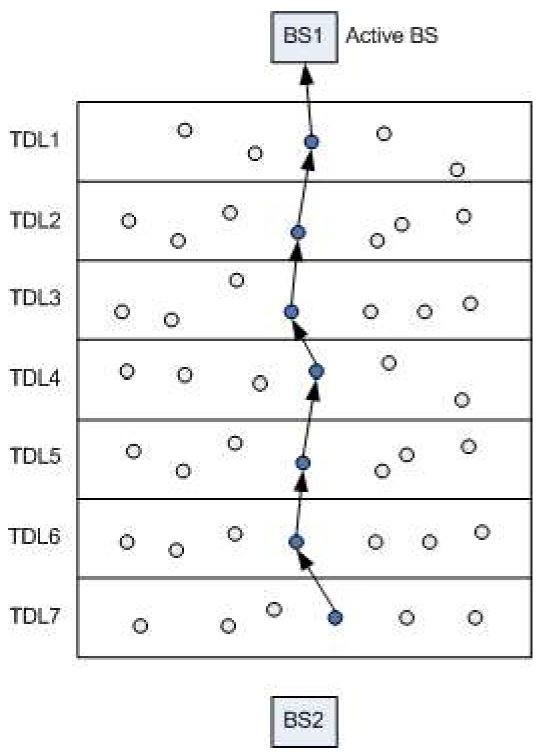

Fig.4: Routing chain

3.2 Transmission Counter to Choose the Lightest Neighbor

The above technique can only ensure the balance of energy dissipation among all nodes in the same routing chain. It can not balance the energy consumptions among the nodes in the same level, which means the horizontal axis. We shall therefore propose another technique, called Lightest Neighbor technique, to solve this problem. The nature of transmission of sensors shown in Fig.5 is broadcasting radial signals in a circle area.

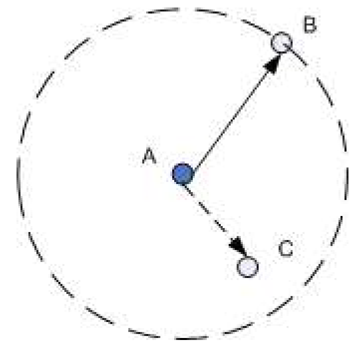

Fig.5: Broadcasting in circle area

Sensor A is transmitting data to sensor B, and sensor C is within the transmitting range of sensor A. Whether it wants or not, the data from sensor A will reach sensor C also. In other protocols, sensor C will discard this packet since it is not a target of this packet. In our approach, however, before discarding the packet, sensor C will count up the number of transmissions of sensor A, called a transmission counter (TC). In our protocol, each sensor node should maintain the list of its closest neighbors, which are the reachable sensor nodes in lower and higher levels next to it, and also the TC corresponding to each neighbor. When a sensor wants to send a data to an ABS, it will look for a next hop in the lower neighbors list in the direction to this ABS. The neighbor which is chosen as a next hop should have the smallest TC. If there are more than two neighbors with the same smallest TC, the one which has highest energy status will be chosen. The chosen neighbor is so called the Lightest Neighbor. By dynamically changing next hop and only choosing the lightest one, the energy dissipation tends to be equal among all nodes in the same level.

3.3 Threshold and data aggregation techniques

Moreover, our approach also adopts the threshold and data aggregation techniques in order to reduce the number of transmissions. Our threshold technique is borrowed partly from TEEN protocol. Depending on applications, each sensor will have a hard threshold, which is the domain of the sensed attribute and a soft threshold, which is a small change in the value of the sensed attribute. The newest values of all attributes are cached in an internal array. The nodes will transmit data only when the following conditions are true: the current value of the sensed attribute is within the interested domain defined by the hard threshold; the current value of the sensed attribute differs from the newest value in the internal array by an amount equal to or greater than the soft threshold. After that, they update the newest value of this attribute by the current value. Unlike TEEN, we might not try to send periodically the thresholds to every node. We do the threshold function not only at sending nodes but also at receiving nodes. Moreover, broadcasting the thresholds is done by the BSs not by any nodes. Therefore, we can avoid broadcasting threshold announcement packets and move the overhead maintenance problems from sensor nodes to BSs. We also do not use any meta-data for negotiations, thus it might reduce the negotiating traffic.

4 Comparisons with other protocols

We evaluate our proposed protocol HOURGLASS by comparing with some popular protocols such as SPIN protocol, Directed Diffusion Protocol, LEACH protocol, TEEN and APTEEN protocols with many metrics referenced in [7] and [8]. The Table 1 lists the compared results.

Table 1: Comparative results

	SPIN	Directed Diffusion	LEACH	TEEN & APTEEN	HG
State Complexity	Low	Low	CHs	CHs	Low
Balance of Energy Dissipation	Very low	Very low	Low	Low	Good
Number of BS(s)	All nodes	1	1	1	2
Radio Signal	No	No	No	No	Yes
Multi-path	Yes	Yes	No	No	Yes
Scalability	Limited	Limited	Good	Good	Average
Negotiation	Yes	Yes	No	No	No
Data Aggregation	Yes	Yes	Yes	Yes	Yes
Query Based	Yes	Yes	No	No	No
Threshold	No	No	No	Yes	Yes

The home environment is significantly appropriate for deploying our protocol. In such environment, sensor nodes are placed densely in a small area, and the number of deployed nodes is moderate. Each sensor node might have many candidates to choose next hop. The distances from this node to its candidates are close, thus the energy consumption to transmit data to each of them is almost same. Therefore, HOURGLASS might use these advantages to uniform the energy dissipation among all sensor nodes. We can obviously see that in our approach the higher density of sensor nodes, the better the balance of energy consumption. This feature, however, is a disadvantage for hierarchical clustering approaches. They will need to pay a higher cost for some heavy overheads such as dynamic clustering, cluster colliding, and cluster head maintaining. Besides, high density of sensor nodes is also appropriate for multi-path based routing. It can make a higher balance in power consumption by changing the route dynamically. Unlike LEACH, TEEN and APTEEN using single-path based routing, we propose a multi-path approach based on Lightest Neighbor technique in order to uniform the power consumption in horizontal direction. Generally, by using our methodology the energy of overall network would be consumed more efficiently than by using other approaches, thus more increasing the network lifetime.

In terms of comparing with data-centric protocols, we also have some adaptations in order to be more suitable for the home environment. The applications of such environment require data delivery to BSs continuously. Such data requirements will not change normally. Therefore, using metadata negotiation and query-based techniques like SPIN and Directed Diffusion should not be appreciated. It might be unnecessary for using extra negotiation packets and querying data from specific sensor nodes. Instead of that, HOURGLASS protocol would be intended to utilize threshold and data aggregation techniques in order to reduce the transmissions of redundant or uninterested data.

5 Conclusion

In this paper, we have described HOURGLASS, a two-base-stations protocol that is near optimal for an energy dissipation balancing problem in wireless sensor networks, especially smart home environment networks. HOURGLASS outperforms the other prominent protocols such as SPIN, Directed Diffusion, LEACH, TEEN and APTEEN in terms of equivalence of energy consumption among all nodes. It can eliminate the overhead of dynamic cluster formation in hierarchical clustering protocols like LEACH, TEEN and APTEEN. It also can limit the number of transmissions among all nodes and much more suitable for home environment than data-centric protocols like SPIN and Directed Diffusion.

In the future we want to improve the synchronization between the two base stations and enhance energy awareness ability of home sensor networks. We hope that our novel protocol will bring out a new wireless sensor network standard for the home environment.

Acknowledgements

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