Evaluation of LEACH Protocol Subject to Different Traffic Models

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Abstract - Different traffic models are introduced to LEACH protocol for wireless sensor network. Network performance of LEACH with these traffic models is analyzed. Our results provide design guidelines for LEACH implementation under a realistic traffic model in which each node has a range of transmission probabilities and for a range of network sizes. Furthermore, by incorporating realistic energy model from Crossbow MICA2 motes, our simulation results also show that LEACH has promising performance when implemented with Crossbow MICA2 motes.

I. INTRODUCTION

Recent advances in micro-electro-mechanical systems (MEMS) technology, wireless communications, and digital electronics have enabled the development of low-cost, low-power wireless sensor nodes that are small in size and communicate untethered in short distances. These wireless sensor nodes, which consist of sensing, data processing, and communicating components, leverage the idea of sensor networks based on collaborative effort of a large number of nodes. Networking together hundreds or thousands of cheap wireless sensor nodes allows users to accurately monitor a remote environment by intelligently combining the data from the individual nodes. These networks require robust wireless communication protocols that are energy efficient, and provide low latency and high throughput.

Low-Energy Adaptive Clustering Hierarchy (LEACH) [1,2] is one of the most popular hierarchical routing protocols for wireless sensor networks. The idea is to form clusters of the sensor nodes based on the received signal strength and use local cluster heads as routers to the sink. This will save energy since the transmissions will only be done by such cluster heads rather than all sensor nodes. Conventional network protocols, such as direct transmission, minimum transmission energy, multi-hop routing, and clustering all have drawbacks that don't allow them to achieve all the desirable properties. LEACH includes distributed cluster formation, local processing to reduce global communication, and randomized rotation of the cluster-heads. Together, these features allow LEACH to achieve the desired properties. Initial simulations show that LEACH is an energy-efficient protocol that extends system lifetime than some general-purpose multi-hop approaches, such as MTE routing and Static-Clustering protocol [1].

In this paper, we expand LEACH protocol research in some aspects. Different traffic models are introduced to the original LEACH protocol. We analyzed network performance of LEACH with these more realistic traffic models and get some conclusions on under what scenarios LEACH has better performance. We used the network simulator NS2 to evaluate performance of LEACH with these new traffic models and compare it to the original LEACH protocol. Our simulation results show that our introducing these new traffic models to LEACH improves network performance in some aspects compared with that of the original LEACH protocol.

II. LEACH with REALISTIC TRAFFIC MODELS

LEACH is a clustering-based communication protocol proposed by the MIT LEACH project. In LEACH, nodes are organized into local clusters, with one node acting as the local base station (BS) or cluster-head. All the other nodes must transmit their data to the cluster heads, while the cluster-head nodes must receive data from all the cluster members, perform signal processing functions on the data (e.g., data aggregation), and then transmit data to the remote base station. Being a cluster head is much more energy-intensive than being a non cluster head node. In order to evenly distribute the energy load associated with a clusterhead and avoid draining the battery of any one sensor, cluster head position is rotated randomly among all the nodes. The medium access protocol in LEACH is also chosen to reduce energy dissipation in non-cluster-head nodes. Since a cluster head node knows all the cluster members, it can act as a local control center and create a TDMA schedule that allocates time slots for each cluster member. This allows the nodes to remain in the sleep state as long as possible. In addition, using a TDMA schedule prevents intra-cluster collisions [1,2].

Although quality of a sensor network is an application-specific and data-dependent quantity, one application-independent method of determining quality is to measure the amount of data (number of actual data signals or number of data signals represented by an aggregate signal) received at the BS. The more data the BS receives, the more accurate its view of the remote environment will be [3].

A. Different Probability of Transmission

In the original LEACH protocol, within a cluster, each cluster member node always sends its data to the cluster head during its assigned TDMA time slot. However, in real world environments, sensor nodes do not always send data all the time. In many cases such as in health monitoring sensor networks, sensor nodes only need to send out data when they received abnormal data [4]. In order to address these kinds of cases using LEACH, we introduce a probability of data transmission for cluster member nodes to send data to the cluster head. During the time slot that a cluster member node is assigned, this node sends data to the cluster head by a probability that ranges from *50%* to *90%*.

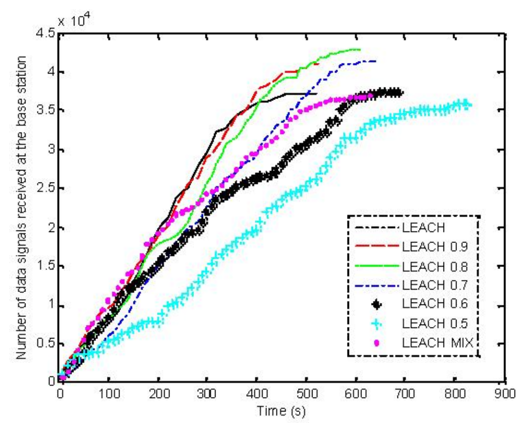

Fig.1 Total amount of data received at the BS over time. Data for the limited energy simulations of LEACH with dfferent probability of transmission Network size is 100.

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Fig. 1 shows the total number of data signals received at the BS over time in LEACH protocol with different probability of transmission. In this figure, caption "LEACH" represents for the original LEACH protocol, "LEACH *0.x*" represents for our extension to LEACH in which nodes sends data to the cluster head by a probability of *0.x*, and "LEACH MIX" represents for LEACH in which mixed heterogeneous probability is applied to cluster member nodes when they send data. In this figure, "LEACH MIX" specifically represents for the scenario that *50%* of total nodes send data to the cluster heads by a probability of *90%*, while the other *50%* nodes send data by a probability of *50%*. Fig. 2 shows the total number of data signals received at the BS over time in LEACH-C protocol with different probability of transmission. LEACH-C is a modified version of LEACH. LEACH-C uses the basestation to broadcast the cluster-head assignment, thus further spreading out the cluster heads evenly throughout the network and extending the network lifetime [1,2]. In Fig. 2, the captions of the curves have similar meaning with those in Fig. 1.

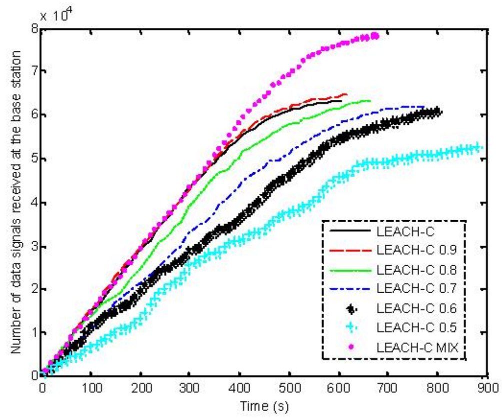

Fig.2 Total amount of data received at the BS over time. Data for the limited energy simulations of LEACH - C with different transmission probability. Network size is 100.

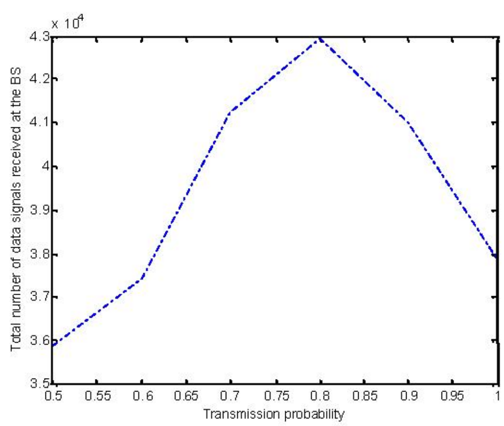

Fig.3 Total amount of data received at the BS at the end of the network lifetime over transmission probability of nodes' sending data. Network size is 100 nodes.

Fig. 1 and Fig. 2 show that when cluster member nodes send data by a probability less than *100%* (not always send data during their assigned time slots) the network has a longer network lifetime. This is an expected result. But decreasing transmission probability doesn't always increase the amount of data signals received at the base station. The reason is that the network has to use more energy in the relatively energy consuming LEACH set-up phases, as there will be more set-up phases when the network lasts for a longer time. There is also overhead within a cluster when a cluster member node doesn't send data in its assigned time slot while the cluster head still have to be kept on. From these simulation results, for data sending probability of *0.7* to *0.9*, amount of data signals received at the base station are better than (sometimes very close to) that of LEACH with original traffic model in which nodes always send data during their assigned time slots. The reason is that in this new traffic model, aggregated data sent by the cluster head to the BS represents data from all the live nodes within the cluster, even if some of them didn't really send data because of the transmission probability which is less than *100%*. Therefore the amount of total data received at the BS can be increased. This is a tradeoff. If the traffic model of a sensor node having a certain transmission probability is adopted, some energy will be saved during the LEACH steady-state phases, but some additional energy will be consumed in the LEACH set-up phases because the network lifetime is longer and there are more formations of clusters. From our simulation results and analysis, as showed in Fig. 3, a probability which is between *70%* and *90%* is favorable for LEACH. In these scenarios, the network achieves a longer lifetime and at the same time transmits more data to the BS.

B. Different Network Sizes

In the paper where LEACH is originally presented [1,2], the network size is 100 nodes. The network performance analysis on LEACH protocol is based on this network size of 100 nodes. While in a real world wireless sensor network deployment there could be many more nodes in the network. In this section, we analyzed the network performance of different network sizes.

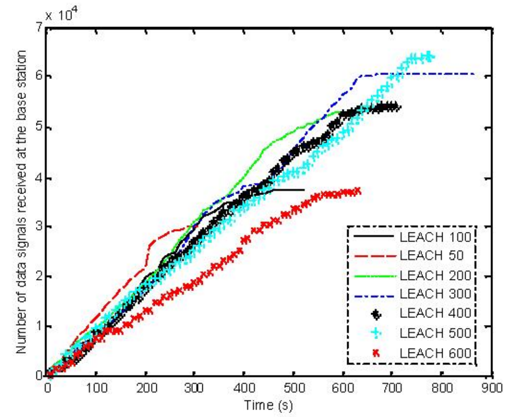

Fig.4 Total amount of data received at the BS over time for different network sizes.

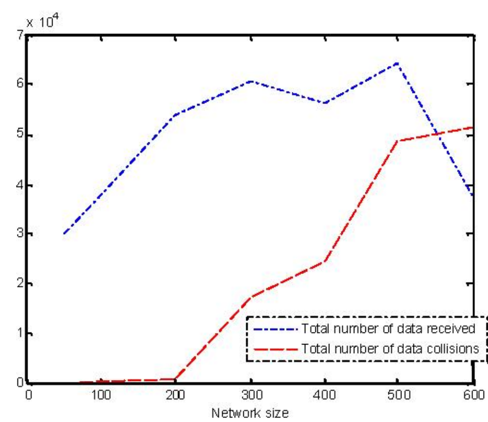

Fig.5 Total number of data signals received at the BS and the total number of data collisions over network size.

Fig. 4 shows the total number of data signals received at the BS over time in LEACH protocol with different network sizes. In this figure, caption "LEACH *n*" represents for LEACH protocol with totally *n* nodes in the network. Fig. 4 shows that network performance in terms of total amount of data signal received at the BS increases when network size increases from 50 to 300 nodes, while network performance decreases dramatically when network size increases from 500 to 600 nodes. The reason is that when network size is too large, data collision instances also increase and therefore network performance decreases. Fig. 5 shows the total number of data signals received at the BS and the total number of data collisions over network size, respectively. Fig. 6 shows the network lifetime over network size. From our simulation results, the performance of LEACH continues to improve for network size up to 500 nodes.

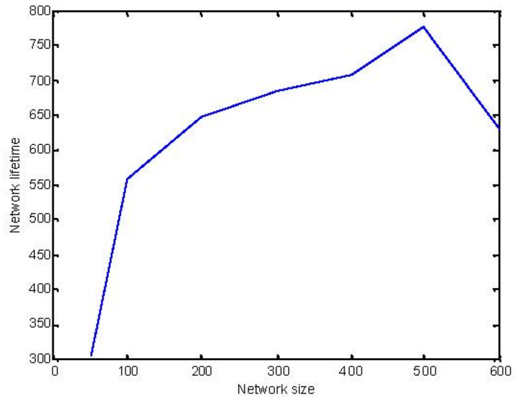

Fig.6 Network lifetime over network size

C. *Incorporating Crossbow Sensor Network Hardware*

Crossbow Technology [5] is one of the leading manufacturers of wireless sensor network hardware. We use their wireless sensor network products, and want to simulate network protocols incorporating Crossbow sensor network hardware. In order to do so, we analyzed the Crossbow MICA2 mote [6] energy model from hardware data spreadsheet of Crossbow [7] and ChipCon (manufacturer of the radio of Crossbow MICA2 motes) [8] and simulated LEACH with Crossbow sensor network hardware power model.

In order to get the Crossbow MICA2 mote energy model, we used our data analysis result from the ChipCon hardware data spreadsheet to get a data table of distance between motes and the corresponding minimal transmitting current required for the motes to communicate with each other successfully. Then we employed a statistical regression analysis method to arrive at the relationship between these two parameters. At last we added power consumption data of all the other parts of a mote to the result. Finally the derived Crossbow MICA2 mote energy model is:

In order to transmit an *L*-bit message at distance *d*, the mote expands:

$$\text{Energy} = L * 1046*10^{-9} + L * d^2 * 22.2*10^{-12}$$
$$\text{when } d < d_{rossover} = 94\text{ m},$$
$$\text{Energy} = L * 1239*10^{-9} + L * d^4 * 0.0016 *10^{-12}$$
$$\text{when } d > d_{rossover} = 94\text{ m},$$

and to receive this message, the radio expends:

$$\text{Energy} = L * 1054 *10^{-9}$$

Fig. 7 shows the total number of data signals received at the BS over time with Crossbow MICA2 mote hardware energy model incorporated. It shows that LEACH and LEACH-C send much more data to the BS in the simulation time than MTE routing and Static-Clustering protocol, which are two general-purpose multi-hop protocols [1]. This simulation result shows that LEACH protocol works well with Crossbow MICA2 wireless sensor network hardware, and has promising performance when implemented with Crossbow MICA2 motes.

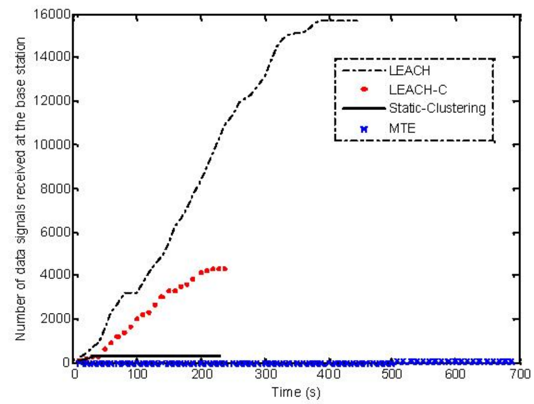

Fig.7 Data for the limited energy simulations of LEACH with Crossbow MICA2 mote hardware data incorporated Total amount of data received at the BS over time. Network size is 100 nodes.

III. CONCLUSION

In this paper, we evaluated the performance of LEACH under a more realistic traffic model in which each node has a range of transmission probabilities. Through our simulation, we provided design guidelines for LEACH implementation. We show that LEACH works well for a networks size up to 500 nodes with each node having a probability of transmission that ranges between 70% and 90%. Furthermore, by incorporating the energy model from Crossbow MICA2 motes, we showed that IEACH hold promising performance for hardware implementation with Crossbow MICA2 motes.

ACKNOWLEDGEMENT

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