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ITJ

ISSN 1812-5638

INFORMATION TECHNOLOGY JOURNAL

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Information Technology Journal 8 (7): 1044-1048, 2009
ISSN 1812-5638

An Energy-Aware Cluster-Based Routing Protocol for Wireless Sensor and Actor Network

[1]Zhicheng Dai, [2]Zhi Li, [1]Bingwen Wang and [1]Qiang Tang
[1]Department of Control Science and Engineering, Huazhong University of Science and Technology, Wuhan Hubei, 430074, China
[2]Patent Agency Center, Huazhong University of Science and Technology, Wuhan Hubei, 430074, China

Abstract: In this study, an Energy-Aware Cluster-Based Routing (EACBR) protocol which adapts to the characteristics of WSAN is proposed. Sensors and actors are divided into some clusters and every cluster including an actor and some sensors is considered to different subnet. The Shortest Path Trees (SPTs) from sensors as resource to actor as destination in every subnet are calculated by Dijkstra algorithm. The process of EACBR protocol is divided into rounds and SPTs are dynamically generated according to network states in each round. The analysis and simulation results show that EACBR protocol can prolong network lifetime and reduce transmission delay.

Key words: WSAN, energy-aware, cluster, shortest path tree

INTRODUCTION

Wireless Sensor and Actor Network (WSAN) derived from Wireless Sensor Network (WSN) refers to a group of sensors and actors linked by wireless medium to perform distributed sensing and actuation tasks. In the network, sensors gather information about the physical world, while actors coordinate and make decisions to perform appropriate actions upon the environment, which allows remote, automated interaction with the environment. The WSAN has wide applications in both civil and military fields such as microclimate control in buildings, home automation and environment monitoring, biological and chemical attack detection and battlefield surveillance (Akyildiz *et al*., 2000; Akyildiz and Kasimoglu, 2004).

In WSAN, the energy efficiency of network communication is also crucial, since sensors are resource-constrained nodes with a limited battery lifetime. The energy-aware routing protocol should take advantage of actor nodes and use their resources when possible.

In this study, EACBR protocol is proposed that enables low packet delay and energy consumption, which constructs the Shortest Path Tree (SPT) among actors and sensors by making use of sufficient energy capabilities, larger memory, better processing and communication capabilities of the actors.

In WSN, many studies on routing protocol are mostly focused on solutions that try to prolong the lifetime of the network. A protocol architecture for sensor network named Low-Energy Adaptive Clustering Hierarchy (LEACH) is developed and analyzed that combines the ideas of energy-efficient cluster-based routing and media access together with application-specific data aggregation to achieve good performance in terms of system lifetime, latency and application-perceived quality (Heinzelman *et al*., 2002). Power-efficient gathering in sensor information systems (PEGASIS) is an improvement of the LEACH protocol (Lindsey and Raghavendra, 2002). Rather than forming multiple clusters, PEGASIS forms chains from sensors so that each node transmits and receives from a neighbor and only one node is selected from that chain to transmit to sink. The LEACH has a drawback that the cluster is not evenly distributed due to its randomized rotation of local cluster-head. For the drawback, MECH (Maximum Energy Cluster Head) routing protocol that has self-configuration and hierarchical tree routing properties is presented by Ruay-Shiung and Chia-Jou (2006). The MECH constructs clusters based on radio range and the number of cluster members.

Shah and Rabaey (2002) proposed to use a set of sub-optimal paths occasionally to increase the lifetime of the network. These paths are chosen by means of a probability function, which depends on the energy consumption of each path. To save energy, maximum Energy routing protocol based on strong head (MESH) is introduced by Lim *et al.* (2007). The collected data from cluster head is transmitted to sink by node defined as a strong head. Tan and Ibrahim (2003) proposed

Corresponding Author: Zhicheng Dai, Department of Control Science and Engineering, Huazhong University of Science and Technology, Wuhan Hubei, 430074, China

PEDAP (Power Efficient Data gathering and Aggregation Protocol), which was a near optimal minimum spanning tree based routing scheme, where one of them was the power-aware version of the other. Boukerche *et al.* (2005) proposed EDA (Energy-Aware Data-Centric Routing algorithm for wireless sensor networks), which represented an efficient energy-aware distributed protocol to build a rooted broadcast tree with many leaves. All the leaf nodes are turned off and all the non-leaf nodes are in charge of data aggregation and relaying tasks. A cluster-based cooperative Multiple Input Multiple Output (MIMO) scheme is provided by Yuan *et al.* (2006). The MIMO reduces the adverse impacts caused by radio irregularity and fading in multi-hop wireless sensor network.

Due to the coexistence of sensors and actors, there exists distinct difference between WSAN and traditional WSN such as node heterogeneity, deployment, coordination. So many protocols proposed for WSN cannot be well suited for the unique features and application requirements of WSAN. In WSAN, Haidong *et al.* (2006) proposed a novel three-level coordination model. In different levels, sensor-sensor, sensor-actor, actor-actor coordination mechanisms are addressed, respectively. But, the realization mechanism is not further discussed. To analyze and solve the coordination and communication problems in WSAN, a sensor-actor coordination model is proposed based on an event-driven partitioning paradigm (Melodia *et al.*, 2007). Sensors are partitioned into different clusters and each cluster is constituted by a data-delivery tree associated with a different actor. The optimal solution for the partitioning strategy is determined by mathematical programming and a distributed solution is proposed.

EACBR PROTOCOL

Here, we present the basic features of EACBR protocol, referring its analysis and simulation.

Routing protocol based on shortest path tree: Figure 1a, is an undirected graph, while the Fig. 1b is the Shortest Path Tree (SPT) that is from node N_1 to other nodes using Dijkstra algorithm. Figure 1c is the Minimum Spanning Tree (MST) using Prim algorithm, which is suitable for dense graph. Since, WSN can be regarded as an undirected dense graph, the routing tree of the network is constructed adopting SPT and MST. By this way, sensor data is transmitted to root node by the routing tree. As shown in Fig. 1, the edge number from left node and intermediate node to root node in MST is more than the one in SPT. In other words, the routing tree rooted at actor node is constructed using SPT, which can reduce the hop count that the data is transmitted from sensors to actors. The transmitting time reduce to some extent. That is to say, the scheme adopting SPT can reduce delay.

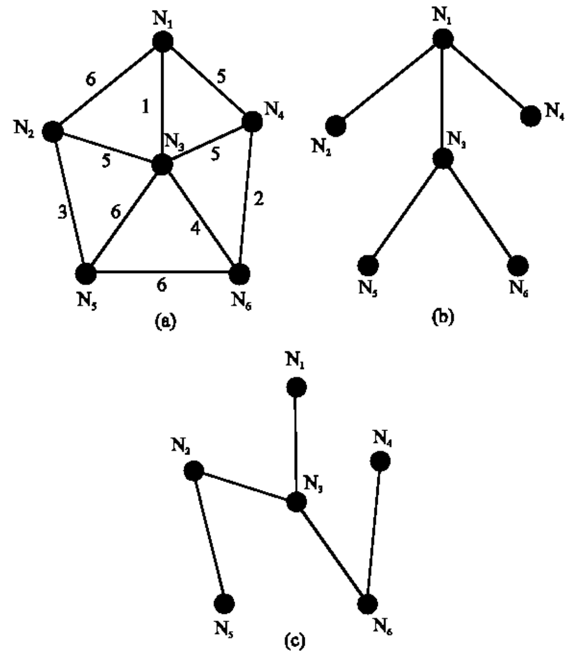

Fig. 1: (a-c) SPT and MST using N_1 as the root

EACBR protocol: Similar to Leach, EACBR protocol configures clusters in every round. The process of EACBR is divided into two phases, which are cluster set-up phase and data transmission phase. The process of network operation is divided into rounds and each round consists of the two phases.

Cluster set-up phase: The operations in the cluster set-up phase are detailed in algorithm 1. Firstly, EACBR protocol is based on the assumption that sensors and actors are already deployed. Sensors and actors are divided into some clusters and every cluster including an actor and some sensors is considered as a different subnet. The cluster set-up phase is as follows: Actor A_i as the cluster head of subnets sends broadcast information in lines 2-4. Sensor N_i receives the information that all actors send because actors are equipped with better communication capabilities and greater transmitting power (line 5). Then sensor N_i is added into the subnet of the actor A_j with the shortest distance from node N_i (lines 6-13). The sensor N_i sends ACK information to the actor A_j with single-hop transmission (lines 14-16).

Algorithm 1: Cluster set-up phase

```
minDistance(i) = ∞
 for each actor A_j do
   A_j → N_i :Broadcast(hello)
 end for
 each actor N_i receives A_j::Broadcast(hello)
 for each sensor N_i do
   for each actor A_j do
     if Distance(N_i,A_j)<minDistance(i) then
       min Distance(i)=Distance(N_i,A_j)
        minDistanceActor(i)=A_j
      end if
    end for
  end for
  for each sensor N_i do
    N_i →minDistanceActor(i)::(ACK)
  end for
```

Data transmission phase: Network nodes are divided into different subnets including an actor and some sensors after cluster set-up phase. Every actor as a cluster head may determine all nodes of its subnet. The SPT from sensors to actor in subnet is calculated by Dijkstra algorithm with the product of the maximum consumption energy of the two nodes in link and the consumption required to send data package as a weight. Then actor sends the shortest path tree structure to all sensors in the subnet. Every sensor can transmit data package along the path of the shortest path tree in its subnet.

The operation of EACBR protocol is divided into rounds. In each round, SPTs are configured and data package is transmitted from sensors to the cluster-head. Repeat the process. The subnet lifetime is expired if the residual energy of a sensor in the subnet is exhausted.

The operations in the data transmission phase are detailed in algorithm 2.

Algorithm 2: Data transmission phase

```
for each round do
   for each subnet do
     Weight(i,j)=E_send(i,j)*max{E_consume(i),E_consume(j)}
     SPT=Dijkstra(Weight(i,j))
     if E_residual(k)≤0 then
       break
     N_i --SPT--> A_j::(Package data)
     end if
   end for
 end for
```

ANALYSIS AND SIMULATION

Here, the analysis and simulation of EACBR protocol are presented.

Preparatory work: According to the study Heinzelman *et al*. (2002), we assume a simple model for the radio hardware energy dissipation where the transmitter dissipates energy to run the radio electronics and the power amplifier and the receiver dissipates energy to run the radio electronics.

To receive k bits, the sensor expends:

$$E_{rx}(k) = kE_{elec} \tag{1}$$

To send k bits a distance d, the sensor expends:

$$E_{tx}(k,d) = \begin{cases} kE_{elec} + k\varepsilon_{fs}d^2, & d < d_0 \\ kE_{elec} + k\varepsilon_{amp}d^4, & d \ge d_0 \end{cases} \tag{2}$$

The electronics energy, E_{elec}, depends on factors such as the digital coding, modulation, filtering and spreading of the signal, whereas the amplifier energy, $\varepsilon_{fs}d^2$ or $\varepsilon_{emp}d^4$, depends on the distance to the receiver and the acceptable bit-error rate.

Energy consumption analysis and simulation: In some hierarchical protocols such as LEACH, randomized rotation of the cluster head positions is used to decrease energy consumption and prolong network lifetime. But in EACBR protocol, actors equipped with longer battery life and better communication capabilities are fixed as the cluster heads in each round. The method (Melodia *et al*., 2007) defined how sensors communicate with actors is proposed, which the objective is to minimize the overall energy consumption by integer linear programming. However, the EACBR protocol is aimed to improve the energy consumption balance of sensors and therefore can prolong network lifetime.

In EACBR protocol, network nodes including sensors and actors are divided into some clusters using location information that every cluster is composed of an actor as cluster-head and some sensors. Every cluster is considered as a different subnet. The shortest path tree from sensors as resource to actor as destination in every subnet is calculated by Dijkstra algorithm with the product of the maximum consumption energy of the two nodes in link and the consumption required to send data package as a weight. The network energy consumption is very low that sensors send data package among the SPT in its subnet.

It is assumed that sensor nodes are randomly deployed in a square area of 400×400 mm. There are four actors which the coordinates (x, y) are (400/3, 400/3), (800/3, 400/3), (400/3, 800/3) and (800/3, 800/3), respectively. The clusters and SPTs are shown in Fig. 2 which the dot denotes sensor and the triangle denotes actor.

In the simulation, the energy and packet parameters of network are shown in Table 1, respectively.

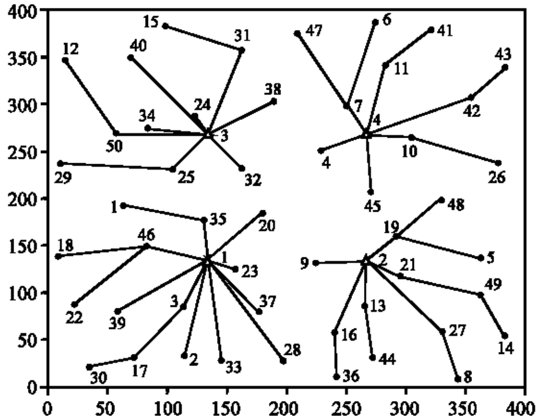

Fig. 2: Network topology

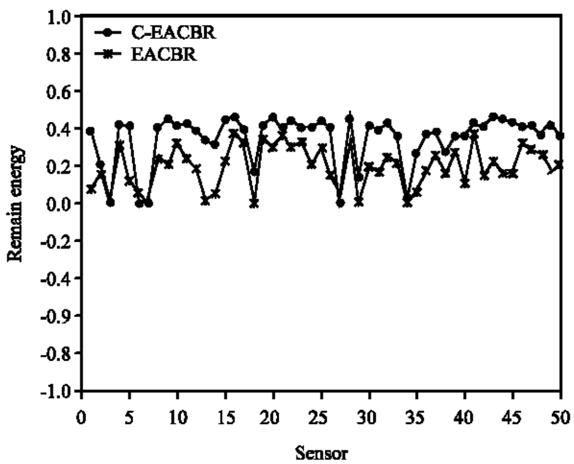

Fig. 3: The residual energy when first sensor dies

Table 1: The values of energy and packet parameters of network

Parameter name	Values
Initial energy	0.5 J
E_{tx}	50e-009 J bit^{-1}
E_{rx}	50e-009 J bit^{-1}
ε_{fs}	10e-012 J/bit/m^2
ε_{amp}	0.0013e-012 J/bit/m^4
Control packet length	200 bits
Data packet length	4000 bits

We consider two different simulation scenarios. The SPTs are constant in each round in scenario 1 named C-EACBR, while they are dynamically changing in scenario 2 named EACBR. In EACBR protocol, the lifetime of each subnet is the time of first sensor dies. Figure 3 shows a comparison of the residual energy in a certain subnet when first sensor dies between C-EACBR and EACBR. Simulation results show that the energy consumption balance of the network is improved by EACBR compared with C-EACBR.

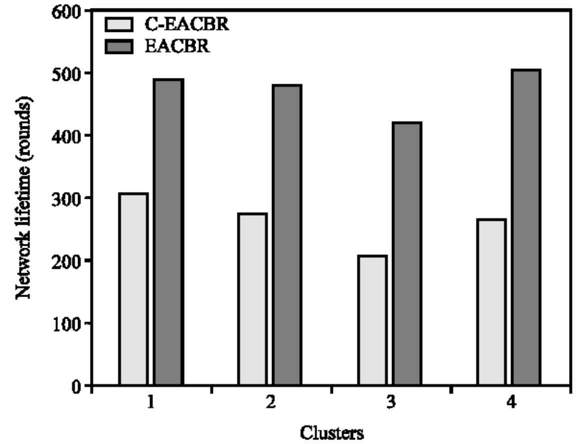

Fig. 4: The lifetime of four subnets

In the simulation, there are four actors which form four subnets. The lifetime of the four subnets in C-EACBR and EACBR is shown in Fig. 4. The simulation results verify that EACBR can significantly prolong the lifetime by 70% compared with C-EACBR.

CONCLUSION

In this study, an energy-aware cluster-based routing protocol named EACBR protocol is presented. Network nodes including sensors and actors are divided into some clusters using location information and every cluster is composed of an actor as cluster-head and some sensors. Every cluster is considered as a different subnet. The shortest path tree from sensors as resource to actor as destination in every subnet is calculated by Dijkstra algorithm. EACBR protocol can save energy and reduce delay that sensors send data package among the SPT in its subnet.

ACKNOWLEDGMENT

This project is sponsored by the National Natural Science Foundation of China under Grant No. 60773190.

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