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AdaptivePlacementof Base Stationsto Alleviate Congestion near Sink Nodesin WSNs

Chorng-Horng Yang[*] and Long-Wei Lin

Department of Information Management, I-Shou University
No. 1, Sec. 1, Syuecheng Rd., Dashu District, Kaohsiung City84001, Taiwan R.O.C.

Abstract: ***Wireless Sensor Networks (WSNs) is a promising technology that can be employed torealize manyversatile applications fordaily life. Sincethe existing congestion control mechanisms used in wired/wireless networks are not tailored to WSNs, a Topology-Aware Resource Adaptation (TARA) approach was proposed tocope with the congestion issue in WSNs. However, the TARA approach does not address the sink hotspot issue.This paper proposed an Adaptive Base-Stations Placement (ABP) approach. The ABP approach can designateseveralsensors with high residual energy as the base stations and can adaptively activate the base stations to relay packets to the sink by making use of a robust scheduling scheme, so that the congestion near sink nodes can be alleviated and the lifetime of the WSN can be improved. To validate the ABP approach, we conduct simulation study. The simulation results show that the ABP approach can evenly schedule the packet transmission to reduce traffic load and can improve the lifetime of the WSN about 16 percent.***

Keywords: WSNs, Congestion Control, Base Station

1. INTRODUCTION

In the last decades, many advances have been made in the area of information technology, wireless communications, sothat the tiny, low cost and low power sensors are available for realizingWireless Sensor Networks (WSNs) [1-3]. Moreover, a variety of versatile applications of WSNs are developed. These applications [4] can be used in ocean water monitoring, tracking object, rescue of avalanche victims, seismic warning system, battlefield surveillance, health care, etc.One of the issues in WSNs is congestion control. When sensor nodes sense the events, they deliver data packets toward the sink. Since there are usually many data packets generated by sensors and, unfortunately, the bandwidth between two sensors is very low, the network congestion, thus, would develop to degrade the throughout and increase the transmission delay. Moreover, much energy is consumed, and the network may seriously collapse.

In [5], an active backpressure (ABPS) mechanism, which allocates bandwidth proportional to the size of tree and makes use of a fairness congestion algorithm to cope with congestion, was proposed. However, as soon as the network enters a crisis state, a high reporting rate is necessary to generate sufficient data to accurately depict the phenomena. Although rate control strategies have been effective to alleviate congestion, they are unsuitable because reducing source traffic during a crisis state is unacceptable. In [6], Kang*et al.* proposed a Topology-Aware Resource Adaptation (TARA) approach, which can build a new topology that has enough capacity to handle the increased traffic by making use of the capacity analysis model. When the congestion is detected, TARA approach can look for a distributor node to detour the path and also look for a merger node which merges the original path and the detour path, so that the congestion in the intersection of two routes can be alleviated. However, the TARA approach does not address the sink hot spot issue.

Since all data packets are routed towards a single sink, the node closer to the sink naturally has heavier workloads, which result in sink hot spot and consume energy more quickly. In this paper, we propose an Adaptive Base-Stations Placement (ABP) approach. The ABP approach can designateseveralsensors that are with high residual energy and located around the sink as the base stations and can adaptively activate the base stations to relay packets to the sink by making use of a robust scheduling scheme. Thus, the sink hotspot issue can be alleviated and the lifetime of the WSN can be prolonged. Moreover, we conduct simulation study to validate the ABP approach.

The rest of this paper is organized as follows. Section 2 briefly discusses the related work. Section 3 presents the proposed ABP approach and Section 4 addresses the simulation study and discusses the simulation results. Finally, Section 5 concludes this paper.

2. RELATED WORK

In the literature, there are several studies dealing with the sink hot spot and trying to prolong the network lifetime. In [7], Oyman*et al.* proposed an approach, which makes use of multiple sinks to share the traffic route toward the single sink and can find the optimal location to deploy the sinks by using the k-means algorithm. Although this approach can distribute the workload and prolong the network lifetime, early failures at sensors that are close to the sink nodes are occurred, since they serve a larger branch set. Furthermore, the mobile sink has been proposed in [8]. Moving sink can redirect traffic flows and help to equilibrate the energy consumption among sensor nodes. The sink makes a moving decision according to the distribution of the residual energy of a small number of sensor nodes and directly moves to the sides of the node with the highest residual energy in the network to consume its energy. However, the strategy brings much overhead on position notification and routing updates. Mobile sink also has been proposed in [9].

In [10], the authors indicated that the gains in network lifetime form sink mobility can be offset by the energy loss caused by frequent network-wide broadcasting because the position notification and routing updates. Thus, the authors proposed the dual-sink approach, which deploys a static sink and the mobile sink. The mobile sink only needs to broadcast within a limited range instead of throughout the network. For those nodes that do not know where the mobile sink is, they send their data to the static sink.

The theory of the placement of the Base Stations (BSs)isprovided in [11]. They proposed the Multiple-Objective Metric (MOM), which can fairly increase various properties instead of the partial property. In this paper, we propose an adaptive base-station placement approach, which is static and sector-based to reduce the overhead of position notification and routing update, to cope with the sink hot spot. The proposed ABP approach can place the BSs around the sink and dividethe BSs into clusters to reduce the workload and enhance the energy efficiency. Moreover, it incurs less overhead and can prolong the network lifetime.

3 PROPOSED ABP APPROACH

The tasks of the proposed ABP approach can be divided into three major parts. (i) The first one is to identify a base station area A_B, which is the area that the sink can communicate with a node directly. After the A_B is identified, all the nodes within the A_B are becoming the candidates of the base station BS_c. (ii) The second part of the tasks is to group these base station candidates into sectors based on the residual energy of the BS_c. And, then, a base station that has the highest residual energy is designated for each cluster and the other base station candidates are becoming backup base stations, which are deactivated to reduce energy consumption and may be activated to be the new base station when the existing base station uses up of its battery energy. (iii) The third part is the tasks to schedule packet transmissions between the sink and the base stations of all clusters. We address the three parts of the tasks of the ABP approach in details in the following subsections.

3.1 Identify the Base Station Area

As the result of the sensor nodes which closer the sink has higher workload and congestion degree, we deployment the BS around the sink and define the base station area as follows.

Definition: (Base Station Area A_B)

Any node n_i that can directly communicate with the sink s is the base station candidates. The area covers all base station candidates is the base station area.

Figure 1 illustrates the base station area. Note that we suppose the sink has a larger communication range than the other nodes have, and the other nodes' communication ranges are different and dependent on their residual energy. Moreover, the sink is responsible for finding and recording the base station candidates.

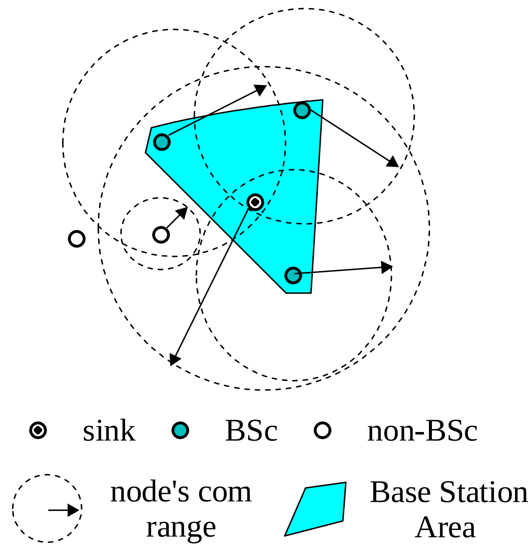


Fig. 1: The base station area.

Figure 2 shows the algorithm for identifying the base station candidates.To find the BS_c, the sink broadcasts a Base Station Search (BSSR) packet. If a node receives the BSSR packet, the node would reply a Base Station Candidates Reply (BSCR) packet to the sink. The BSCR packet carries the node's address and the current residual energy. When the sink gets aBSCR packet from node n_i, it should replies a Base Station Candidate Confirmation

Proc SinkIdentifyBSc(){
S1: s broadcasts a BSSR packet
S2: **IF** s receives a BSCR packet from n_i
THEN {
s replies a BSCC packet to n_i and
Add (n_i addr, energy) into BSc list
}
S3: Repeat Step 2 until timeout
}

Proc NodeReactToSink(){
IF n_i receives a BSSR packet
THEN {
n_i replies a BSCR packet to s
IF n_i receives a BSCC packet from s
THEN n_i change state to BSc and quit
ELSEIF timeout occur **THEN** quit }
}

Fig. 2: Identify BSc.

(BSCC) packet to n_i and records n_i as the base station candidate as well as the address and residual energy of n_i in a base station candidate list. On the other hand, the node n_i will change itsstate into base station candidate as it receives BSCC packet from the sink.

3.2 Cluster the Base Station Candidates

After the sink identifies the base station candidates, it can obtain a BSc list. Suppose there are k_c base station candidates in the list and these base station candidates would be grouped into c clusters. Then, the sink can invoke the procedure shown in Fig. 3 to classify the base station candidates into clusters. We address the algorithm as follows.

At the sink end, the sink first sorts the list of the base station candidates according to the residual energy. Then, the sink picks the unmarked base station candidate, say n_i,

Proc SinkClusterBSc(){
S1: s sort BSc List according to energy
S2: **DO WHILE**(unmarked BSc in the BSc List exists){
S3: s picks the BSc n_i that has the highest energy to be the BS and sends a CCM packet to n_i, then wait
IF s receives a RCM packet from n_i **THEN**{
S4: s marks n_i as BS and marks $\forall n_j \in C(n_i)$ to be BS_b and replies a CC packet to n_i
S5: s activates n_i to be BS and deactivates $\forall n_j \in BS_b$ }
END /end for DO WHILE
}

Proc BScReactCCM(){
IF n_i receives a CCM packet **THEN** {
n_i broadcastCCM packet to other BSc
n_i selects $k \le \lceil (k_c - c)/c \rceil$ BSc that has replied quickly to join the cluster, and replies a RCM packet to s
IF n_i receives CC packet **THEN** quit}
}

Fig. 3: Cluster the BSc.

that is with the highest residual energy to be the base station, and sends a Collect Cluster Member (CCM) packet to n_i. When n_i successfully collects its cluster members, n_i replies a Reply Cluster Members (RCM) packet, which carries the cluster members' addresses and residual energy information, to s. Then, s marks n_i as the base station (BS) and also marks each cluster members as backup base stations (BS_b) for this cluster, and then replies a Cluster Confirmation (CC) packet to n_i. Here, we denote the cluster associated with the base station n_i as $C(n_i)$. Thereafter, s activates n_i to act as the base station of this cluster and deactivates $\forall n_j \in BS_b$ in this cluster to save energy. Thus, the sink repeats the above procedure until all base station candidates is marked as either BS or BS_b.

On the other hand, a base station candidate n_i that receives a CCM packet from s has to broadcast its CCM packet to the other base station candidates. Then, n_i would select k base station candidates that have replied quickly to the CCM packet to be the cluster members. Here, the number k satisfies the following condition $k \le \lceil (k_c - c)/c \rceil$. Then, n_i replies a RCM packet, which records all the cluster members for $C(n_i)$, to s.

So, after executing the above algorithms, the base station candidates are classified into clusters to be either the active base station or sleeping backup base stations. Since the node n_i selects the base station candidates that replied to join the cluster quickly to be the members, the cluster members, thus, are expected to be located nearby. Figure 4 illustrates the clusters, the BS, andthe BS_b for $k_c = 11$

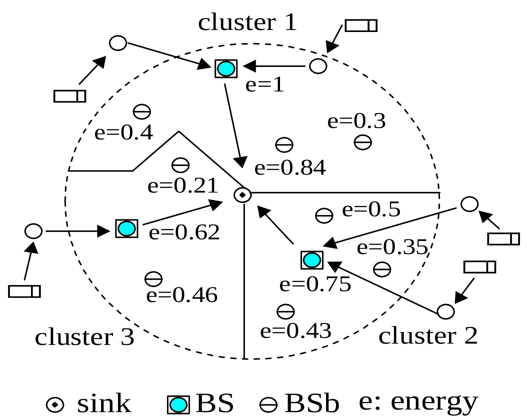


Fig. 4: Illustration of clusters.

and $c = 3$.

3.3Robust Scheduling Scheme

After clustering the base station candidates, there will be only one active base station in each cluster and the backup base stations are deactivated to save the energy. Thus, a source node could transmit its data packet to one of the active base stations according to the routing scheme adopted in the WSN. However, the base station may consume its energy quickly, since a large number of data packets from different sources are routed to the base stations. In [12], Hashmi*et al.* reported that when the BS'energy is not enough, the cluster falls in unstable situation, which may cause packet loss. Thus, a robust scheduling scheme is required to activate a backup base station to replace the current low-power active base station.

First, we assume the data transmission between the sink and the active base stations is based on TDMA scheme in this study. The TDMA scheme is controlled by the sink to avoid transmission contention among the active base stations. Thus, the overall power consumption in the base station area can be reduced and the lifetime of the WSN is also improved. So, based on the TDMA scheme, we assume that each active base station can transmit at least one data or control packet during a maximum time period of Δt_s.

Proc SinkManageBS(){
S1:**IF** s receive a BSLP packet from BS_i
THEN {
S2: s picks a BS_b in the cluster of
BS_i thatis with highest power and
activates the BS_b to be new active
base station BS_j
S3: s sendsNBSR packet to BS_i
}
S4: **IF** s receives a BSRT packet from BS_i
THEN {
s marks BS_i as retired and BS_j as active base
station in this cluster}
}

Proc ActiveBSRetire(){
IF BS_i detects low power state
THEN {
BS_i sends a BSLP packet to s
IF BS_i receives a NBSR packet from s
THEN{ BS_i stops relaying new data
packet. When buffer of BS_i is empty,
BS_i send BSRT packet to s }
}
}

Fig. 5: Robust scheduling scheme.

Figure 5 shows the algorithm for managing the active and backup base stations. When the sink receives a Base Station Low Power (BSLP) packet from a base station BS_i, the sink would pick the backup base station that belongs to the cluster of BS_i and is with the highest power. Then, the sink activates this backup base station to be a new base station BS_j, and sends a New Base Station Ready (NBSR) packet to BS_i. Thereafter, when the sink receives a Base Station ReTire (BSRT) packet from BS_i, the sink marks the BS_i as retired and BS_j as active basestation.

In contrast, when an active base station BS_i detects its low power state, it would send a BSLP packet to the sink. Thereafter, when BS_i receives a reply with NBSR packet from the sink, BS_i would not receive new data packets from sources to relay them to the sink and just relays the data packets stored in its buffer. As the buffer of BS_i is empty, BS_i will notify the sink with a BSRT packet and goes into sleeping mode.

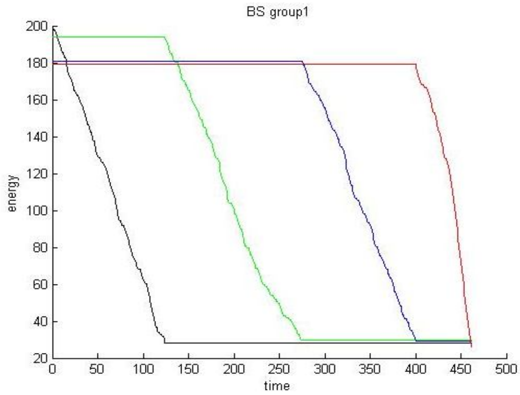
4 Simulation Study

4.1Simulation Model

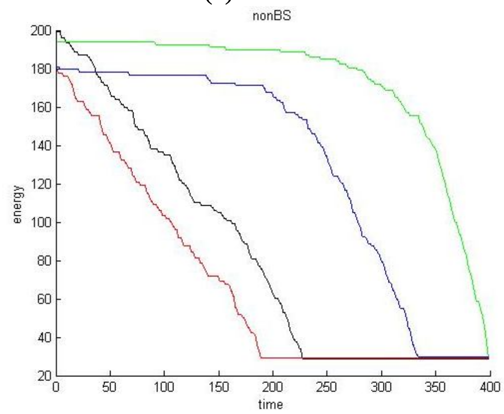
We have conducted simulation experiments by making use of MATLAB. The size of the WSN is fixed in a 200m by 200m square area. The sink is deployed at the center of the area, and the sensor nodes are randomly distributed. The transmission range of the sink is a circle area with the radius of 10-35 meters, and the transmission range of the sensor node varies between 2 meters to 10 meters according to the node energy.

We compare the ABP approach against the Non-BS approach, which is without base stations. We are interested in the following behavior of the ABP approach: (i) the power consumption of the base station and (ii) the lifetime improvement. Note that we denote the lifetime improvement as ΔL, which is defined as the difference between the lifetime of a WSN with the ABP approach and the lifetime of a WSN without base stations.

On the factors that can affect the above experiment outcomes, we consider the following factors: (i) applications (i.e., object tracking and event monitoring) (ii) cluster sizes, (iii) event rates, and (iv) node density. Note that for the non-BS approach all the sensors located in the base station area can relay the data packets to the sink, so that the collision may occurred frequently. The probability of collision for the non-BS approach is referred to [13] and given as Eq. (1).



(a) ABP



(b) Non-BS

Fig. 6: Validation of the approaches

$$p_{collision} = 1 - \frac{N}{CW} \sum_{k=1}^{CW-1} \left(\frac{CW-k}{CW} \right)^{N-1}, \quad (1)$$

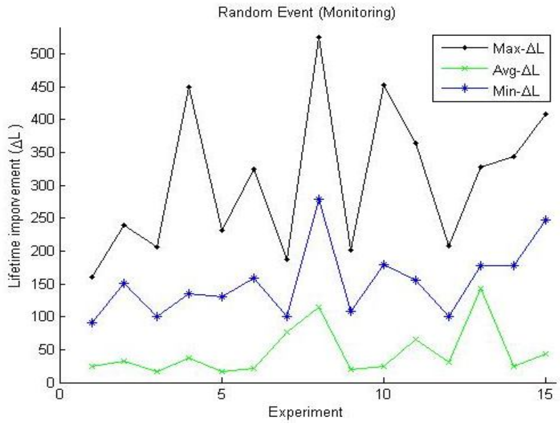
where CW is contention window, and N is the number of contending transmissions.

4.2Simulation Results

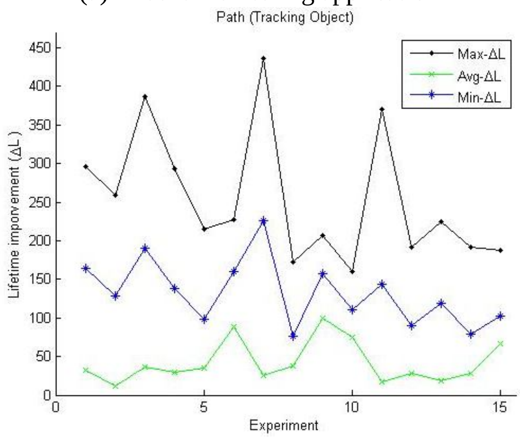
WE ADDRESS THE SIMULATION RESULTS ASFOLLOWS.

(a) Validation of the ABP approach: Figure 6(a) shows the power consumption of the base stations in a cluster for the ABP approach, and Fig 6(b) demonstrates the power consumption of the sensor nodes located near the sink for the non-BS approach. Obviously, the ABP approach works correctly, since the active base station is handed off from the BS with the highest power to the BS with the lowest power according to the proposed algorithms. In contrast, for the non-BS approach, all the sensor nodes are responsible for relaying packets and thus consume their power concurrently. This simulation results show that the lifetime improvement is about 16.1 percent (ABP: 462 and Non-BS: 398).

(b) Lifetime improvement: Figure 7 shows the lifetime improvement (ΔL in terms of unit time) of the ABP approach for two different applications. The maximum



(a) Event monitoring application



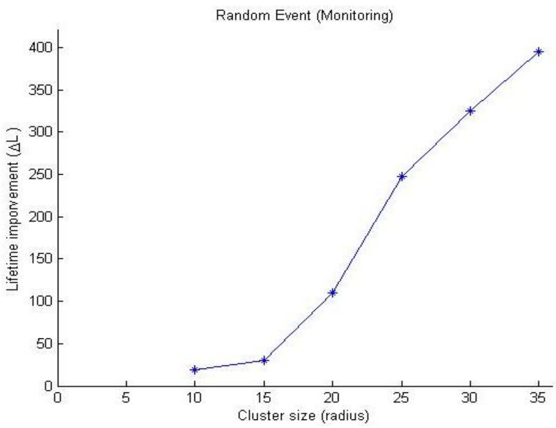
(b) Object tracking application

Fig. 7: The base station area.

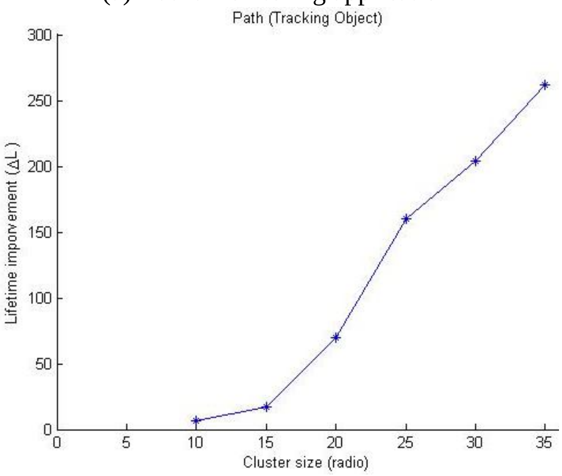
ΔL represents the maximum lifetime improvement among the clusters, and, similarly, the minimum ΔL represents the minimum lifetime improvement among the clusters. The average ΔL is the average value of ΔL for all the clusters. The simulation results show that the ABP approach can achieve much lifetime improvement for the object tracking application than the event monitoring.

(c) Cluster size vs. lifetime improvement: Figure 8 shows the different cluster sizes and the corresponding lifetime improvement. As the cluster size increases, more sensor nodes can be selected as the base station candidates, so that the lifetime of the WSN can be improved much. However, the lifetime of the WSN for object tracking application is improved less than that for event monitoring application.

(d) Event rate vs. lifetime improvement: Figure 9 shows the lifetime improvement for different source data rates. The higher source data rate means more data packets are generated and, thus, the lifetime improvement is degraded. Similarly, the event monitoring application has the better lifetime improvement than the object tracking application.

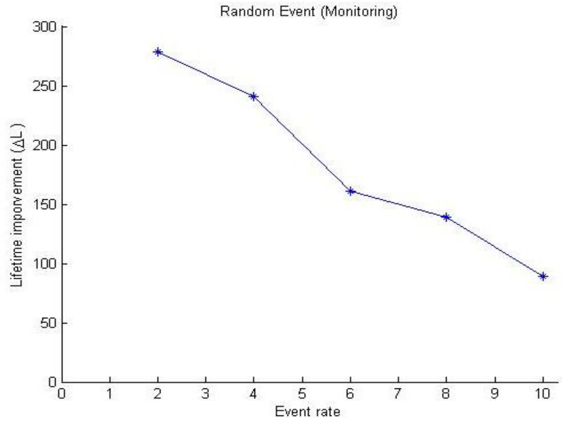


(a) Event monitoring application

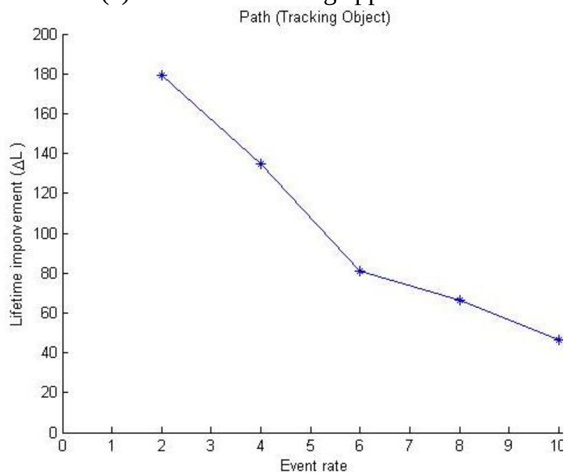


(b) Object tracking application

Fig. 8: The cluster size.



(a) Event monitoring application



(b) Object tracking application

Fig. 9: Data rate at source.

5 Conclusions

Wireless Sensor Networks (WSNs) is a promising technology that can be employed torealize manyversatile applications forour daily life. Sincethe existing congestion control mechanisms used in wired/wireless networks are not tailored to WSNs, we proposed an Adaptive Base-Stations Placement (ABP) approach, which can designateseveralsensors with high residual energy as the base stations and can adaptively activate the base stations to relay packets to the sink by making use of a robust scheduling scheme. Thus, the sink hotspot issue can be alleviated and the lifetime of the WSN can be improved. To validate the ABP approach, we conduct simulation study. The simulation results show that the ABP approach can improve the lifetime of the WSN about 17 percent. And, the larger cluster size or the higher node density can achieve much lifetime improvement for the ABP approach. In contrast, higher data rate at source nodes would degrade the lifetime improvement of the ABP approach.

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AUTHOR

Chorng-Horng Yang received the B.S. degree in Electrical Engineering in 1992 from National Taiwan University of Science and Technology, and M.S. and Ph.D. degrees in Electrical Engineering from National Chung Cheng University, Taiwan, in 1994 and 2001, respectively. In 1999, he was a visiting scholar at the Ohio State University, USA; and from 2005 to 2007 he was the Chief of Networking Section of Computer Center in I-Shou University, Taiwan. He is currently an assistant professor at the Department of Information Management, I-Shou University. His research interests include information systems, wireless networks, performance analysis, and protocols.

Long-Wei Lin had graduated from the Department of Information Management, I-Shou University, Taiwan.