A Concentric-based Sleep Scheduling Scheme for Wireless Sensor Networks

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Abstract—In Wireless Sensor Networks (WSNs), how to extend the lifetime is an important issue. Our research uses Sleeping Scheduling scheme which divides the network into many concentric layers and rotates sensors in different odd and even layers to sleep. By our scheme, we can balance the power consumption among all sensors and reduce power and transmission load of sensors near sink. Our research use Transmit Power Control (TPC) technique to control topology and divide concentric layers, and use the topology to transmit packets to sink. Finally, the performance of our scheme is better than other Sleeping Scheduling schemes in the simulations.

Keywords: Wireless sensor network (WSN); Lifetime; Sleep Scheduling; Concentric layer

I. Introduction

Due to the booming network technology, in order to provide many convenient services, types of different wireless networks are studied and applied in our daily life, especially Wireless Sensor Networks (WSNs) [1], which is a successful example of combine sensor and wireless network.

Wireless sensor networks are made up of hundreds to thousands of small, cheap and low-power wireless sensors, and each sensor have sensing, communication and calculated function. These sensors can be deployed in areas that need to be monitored for sensing changes in the surrounding environment and gather information, and then use wireless communication transmission way to create multi-hop [2] path to the data collection (Sink) center or the base station for collection and computing. That can help for monitoring environmental, military surveillance, medical care, and so the application can provide considerable assistance, so the wireless sensor networks research in recent years has been widely discussed and studied [1].

However, the sensors in WSN due to small size and low cost, the sensor performance is usually has a battery energy, storage space and computing power are constrained features, the battery cannot be replaced or supplemented, so that the efficient use of power is the focus of attention of many studies [3].

Existing study of wireless sensor networks, there are many ways to extend the wireless sensor network life cycle, and sleep scheduling mechanism [4] is an effective and common way to make idle senses enter sleep in order to reduce the power consumption of the sensor, so how to arrange the sensor sleep schedule without affecting the normal operation of the whole network is a very important issue.

But sleep scheduling mechanism accompanied by many conditions need to be considered, such as routing interrupts these conditions, packet delay, data loss and other issues, the sensor will cause additional power. The goals of this paper are as follows. First, balance the power consumption of sensors. Second, reduce the transmission message is interrupted. Third, reduce the waiting path sensors functioning of the power consumption caused by the delay. Fourth, ease the hot spot issue [5] in WSN.

II. Related Work

In the literature, there have been many sleep scheduling mechanism is proposed to reduce power consumption and extend the network lifetime, we will explore the following to be applied in our study, the transmission power control techniques [6] and sleep scheduling mechanism [4].

A. Transmission Power Control (TPC) techniques

Transmission power control techniques can be applied to different targets, the general application in the wireless network topology control and channel utilized to transport energy consumption. Expect to meet with the lowest power consumption wireless network connectivity and certain quality of communication.

The Adaptive Transmission Power Control (ATPC) [7] is a lightweight algorithm of adaptive TPC for WSNs. Each sensor creates a model for each of its neighbor sensors, describing the correlation between link quality and transmission power. With the model, which employ a feedback-based transmission power control algorithm to dynamically maintain individual link quality, and figure 1 is the mechanism of feedback loop for ATPC.

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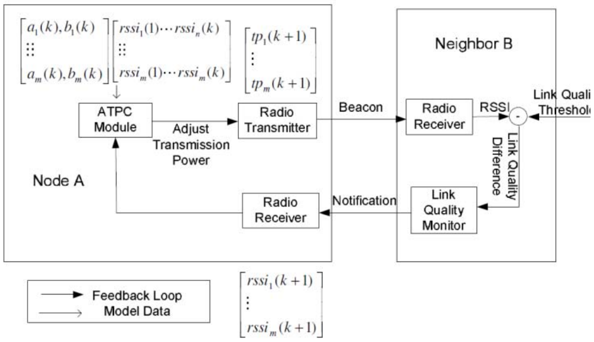

Figure 1 Feedback Loop Overview for ATPC

B. Sleep scheduling mechanism in wireless sensor network applications

In existing mechanism can be divided into the following three types, On-demand, Asynchronous, and Scheduled rendezvous [4].

In On-demand Sleep scheduling mechanism, sensors will wake up the next sleeping sensor in the route, that can reduce the waiting time for the sensor to operate waking reduce power consumption. In Pipelined Tone Wakeup (PTW) [9], the sensor needs transmission will broadcast Wake-up Beacon for waking up all neighbors, and communicate to the sensor in route, and show in figure 2.

However, sensors must open low-power channels (Low Power Wakeup Radio) for waiting to be awakened, the power consumption will be higher than normal total sleep mechanisms, and this low-power wake-up channel is limited, that cannot do remote wake-up.

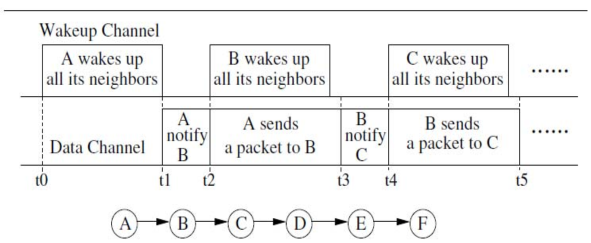

Figure 2.Pipelined Tone Wakeup (PTW)

Asynchronous sleep scheduling mechanism is the basic and earliest full-sleep sleep scheduling, each sensor's duty cycle is not fixed, and figure 3 show the duty cycle of sensors in Asynchronous sleep scheduling mechanism. In Probing Environment and Adaptive Sleeping (PEAS) [10], Sensors need to detect whether the neighboring sensors in operate state, if there is no sensor is working nearby, it will remain active until the exhaustion of their power. And vice versa if the neighboring sensors are active, it will follow its sleep probability to decide whether to sleep or not.

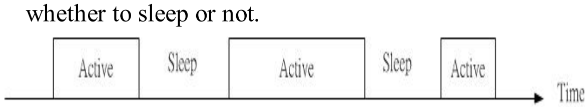

Figure 3 Asynchronous sleep scheduling mechanism

In Scheduled rendezvous sleep scheduling mechanism, each node should wake up at the same time as its neighbors and go to sleep until the next rendezvous time. Sensor-MAC (S-MAC) [11] is earliest scheduled rendezvous sleep scheduling, sleeping sensors after periodic intervals wake up and receive/save their data from their neighbors. S-MAC enhances energy efficiency to a great extent at the cost of increased delay. In Delay Efficient Sleep Scheduling (DESS) [12] and Energy Efficient TDMA Sleep Scheduling [13], time is divided in frames and each frame consists of a certain number of time slots, sensors are assigned to a lot slots per frame, according to a certain scheduling algorithm, and uses such slots for transmitting or receiving packets to or from other sensors. However, they have several drawbacks, they have limited flexibility, and need tight synchronization and they are very sensitive to interference.

Sleep/Wake Scheduling Scheme for Minimizing End-To-End Delay (SMED) [14] focus on transmission delay problem, this mechanism set sensors in important communications positions more wake-up time to reduce data transmission delay, and save power in sensors waiting for transmission, but this would be too long so that part of the sensor operation and may cause hot spot issue, and shorten the network lifetime.

III. A Concentric-based Sleeping Scheduling Scheme for Wireless Sensor Networks

This chapter will discuss the sleeping scheduling scheme we proposed and to overcome the problem in WSNs. The objective of this paper is as following: (1) to balance sensor's power consumption; (2) to reduce the transmission message interrupt; (3) to reduce the power consumption caused by transmission delay; (4) to ease hot spot issue in wireless sensor networks.

A. Network environment and assumption

In this paper, the environment of WSNs, lots of sensors are uniformly deployed in the range wherever you want to monitor. When sensors are deployed, they can't move anymore and the computing, memory and battery are limited. Each sensor nodes has wireless communication, which can transmit detected data via wireless. There have a sink node, which has unlimited power, better computing capability then other nodes and in the center of network area and be set as in layer 0. Normal nodes will send detected data to sink node by multi-hop transmission, and sink node will use collectively.

In our scheme, each sensor use transmission power control technology, so that each sensor and sink can transmit data through different transmit power levels to a particular sensor at different distances. In following steps, we can describe in the three parts: Create concentric and routes, sleep scheduling, transmit packet, and figure 4 is the flow chart of main step of our scheme.

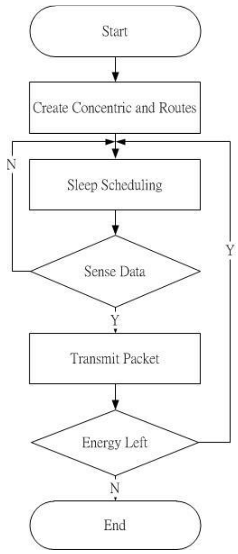

Figure4. The flow chart of our scheme

B. Create concentric and routs

When wireless sensor nodes settle down, network will start to create concentric and routs. Therefore, at the first, we define sensor information tables. Second, we build concentric architecture and routing.

To make each sensor knows their associated data, we need to create following three tables: Owner Information Table (OIT), Variable Information Table (VIT), Neighbor Information Table (NIT). OIT will record the data sensors should know, and data will not change anymore after recoded. VIT records data will continue to update or change, and status 5 mean sensors will have not enough power to work. NIT records data of neighbor sensors can communicate each other. The detail as table 1, table 2 and table 3.

Table 1.Owner Information Table

Threshold_Time	Layer	Duty Cycle

- Threshold_Time：The value decides whether to extend Wake up_Time.
- Layer：Which layer is sensor in, and be set "Null" initial.
- Duty Cycle：Sleep_Time + Wake up_Time

Table 2.Variable Information Table

Energy	Status	Packet_ID

- Energy：Energy will be changed over time.
- Status：Sensor's current status
- 1：transmit；2：receive；3：wake up； 4：sleep； 5：low power

- Packet_ID：The id of the packet be transmitted or received, and be set "0" initial.

Table 3.Neighbor Information Table

NeighborID	Neighbor Layer	RSSI

- NeighborID：Neighboring sensors.
- Neighbor Layer： Which layer is neighboring sensor in.
- RSSI（Received Signal Strength Indicator）: Value of RSSI.

After sensor defines all tables, we need to define the communication distance of sensor and data of Route_Message packet for create routes. If sensor receives the Route_Message packet and value of layer data in OIT is null, then Sender_Layer + Power level= receiver's Layer. The detail is in table 4.The relationship of communication distance show in figure 5. Ld is the distance between each layer. Rc is the max communication distance of sensor. Rc = Ld *3 ensure that sensor belongs to the same odd or even layer have the long-longest communication range.

Table4. Route_Message packet

SenderID	Sender_Laye	Power level

- SenderID: The ID of which sensor send this message.
- Sender_Layer: Which layer is sender in.
- Power level: How much power level sender use.

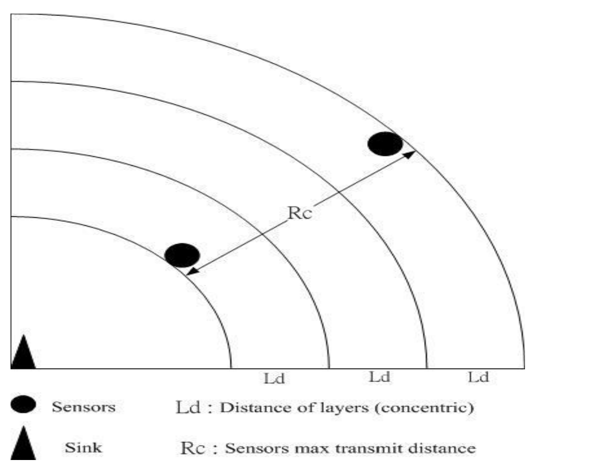

Figure5. The relationship of communication distance

When defined all the data we need to use, then we can start to build concentric architecture and routing.

First, sink broadcasts 1 power level Route_Message, and sensors receive this message will update OIT and NIT, and sink broadcasts 2 power level Route_Message to sensors, and sensors receive this message will update the table OIT and NIT, it shows in figure 6 and figure 7. Second, sensors in layer 1 broadcast 2 power level Route_Message, and sensors in layer 2 and 3 receive this message will update the layer 3's NIT and OIT, sensors in layer 2 update NIT, and sensors in layer 2 broadcast 2 power level Route_massege, sensors in layer 4 update OIT and NIT, and sensors in layer 3 update NIT, it shows in figure 8 and figure 9. And so on, sensors in layer 3 broadcast 2 power level Route_massege, sensors in layer 5 update OIT and NIT, and sensors in layer 4 update NIT. After keep running above step, all sensors will update there OIT and NIT. The flow chart of this step is in figure 10.

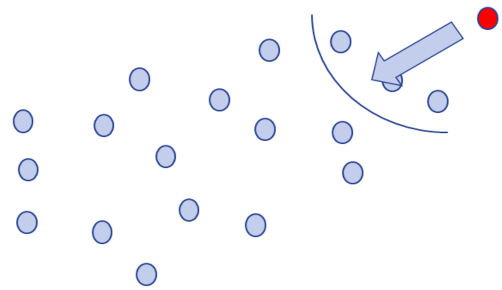

Figure6. Sink broadcasts 1 power level Route_Meaasge to Layer 1.

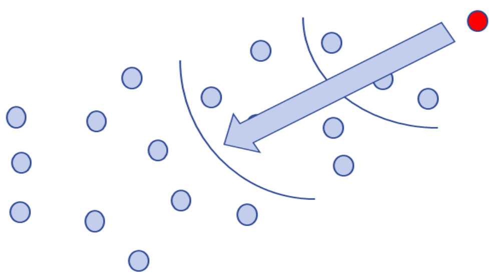

Figure7. Sink broadcasts 2 power level Route_Meaasge.

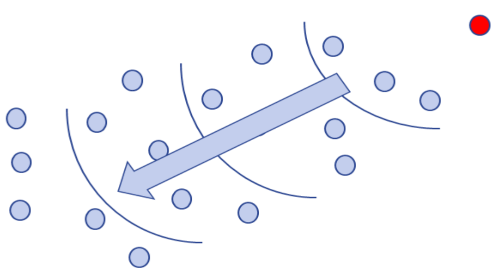

Figure8. Sensors in layer 1 broadcast 2 power level Route_Meaasge.

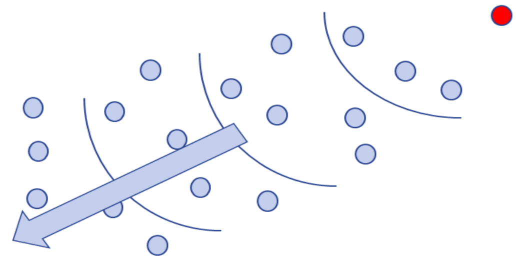

Figure9. Sensors in layer 2 broadcast 2 power level Route_Meaasge.

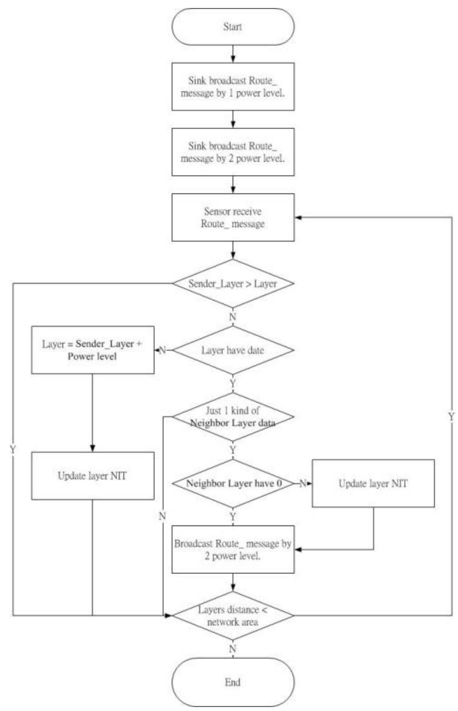

Figure10. Flow chart of Create concentric and Routes

C. Sleeping Scheduling

When sensors have created information NIT and OIT itself, the sensor immediately into the overall network operation phase, and initiates sleep scheduling mechanism operates to diversify power consumption.

In Sleep Scheduling step, Sleep_Time = Wake up_Time, when sensors in odd layers is in Sleep_Time, sensors in even layers will in Wake up_Time, and vice versa. When sleep scheduling mechanism begin, sensors arranged in odd layers area and even layers alternating work to sustain the entire network operation. First, the sensors in the odd layers (Layer mod 2 = 1) first into operation (Wake up_Time) determine by layer data in OIT. Each sensor is responsible for sensing the surroundings and to generation information, if new information is sensed, the sensor pick one most near neighbor sensor form NIT and send the data to this sensor in odd layers. If no event occurs, sensors will standby until duty cycle end determine by data in OIT. After that, sensors in odd-layer go to sleep (Sleep_Time) to save power.

Then to take over the work of the sensors in odd layer, the sensors in the even layers (Layer mod 2 = 0) into operation (Wake up_Time) determine by layer data in OIT. Each sensor is responsible for sensing the surroundings and to generation information, if new information is sensed, the sensor pick one most near neighbor sensor form NIT and send the data to this sensor in even layers same. If no event occurs, sensors will standby until duty cycle end determine by data in OIT. After that, sensors in even-layer go to sleep (Sleep_Time) to save power. Figure 11 is the situation of sleep cycle alternating, figure 12 is the timeline situation of sleep cycle alternating, and figure 13 is the flow chart of Sleep scheduling.

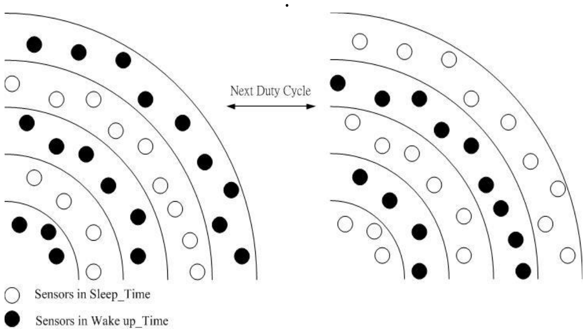

Figure11. Situation of sleep cycle alternating

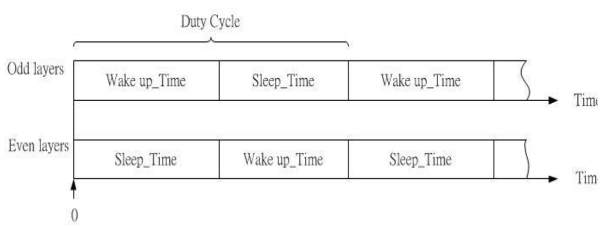

Figure12. Duty cycles of sensors in odd or even layers.

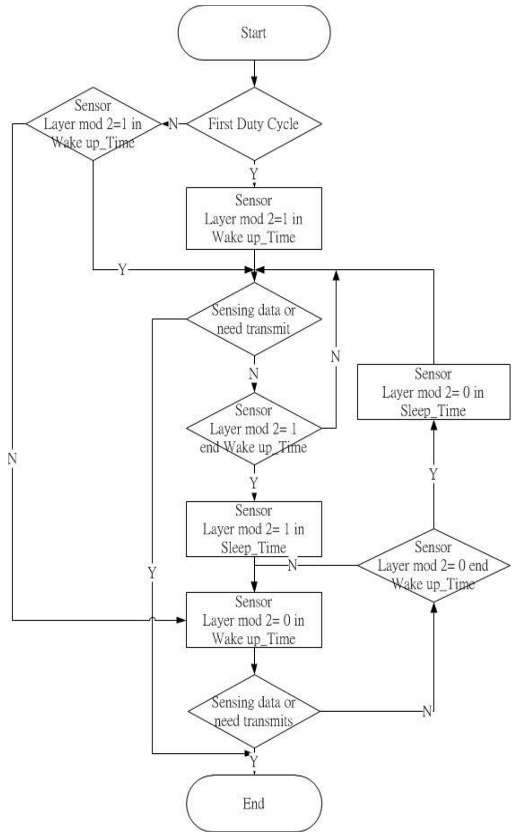

Figure13. Flow chart of Sleep Scheduling

C. Transmit Packet

When the entire wireless sensor networks into operation, sensors that detect the message must use other sensors to transmission data by way of multi-hop transfer until the data arrives at the data center. At first step of transmission, sensors need to send packets will determine the operation of their OIT if already close to the end of the period. If Wake up_Time > Threshold_Time, mean sensors have plenty time for packet transmission, and sensors will send packet to the sensor in same odd or even layer and closer to sink in NIT, and we call this General Transmit. It shows in figure 14.

In another situation, if Wake up_Time < Threshold_Time, mean sensor has not plenty time for packet transmission, and this sensor will go to sleep soon. With this situation, sensor extends their operating time, and reserves the message packet need to send until sensors in different odd or even layer wake-up. Once sensors in different odd or even layer wake-up, it transmit packet to neighbor sensor in different odd or even layer closer to sink, and go to sleep immediately. After this situation, sensor not changes its duty cycle, we call this Special Transmit. Its purpose is to ensure the continuity of transmission, and reduce extra energy waste by packet transmission interrupt or delay. The situation is showed in figure 15. Figure 16 is the flow chart of Transmit packet step.

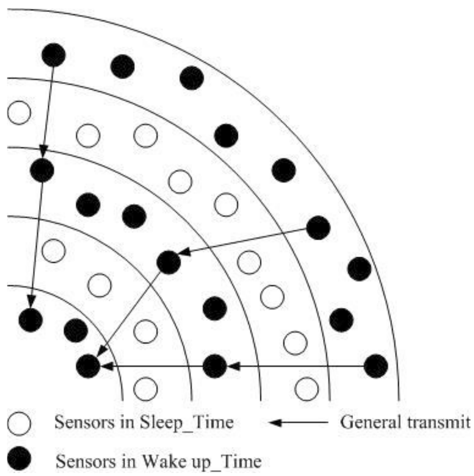

Figure14. Situation of General Transmit

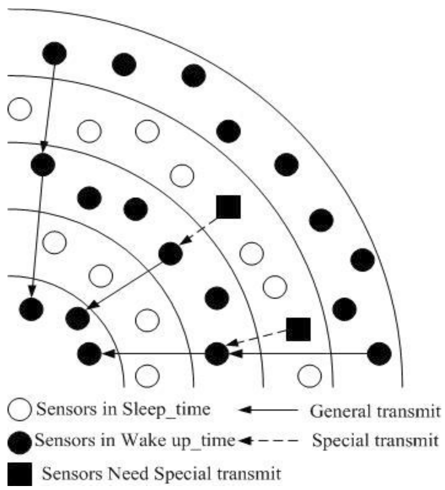

Figure15. Situation of Special Transmit

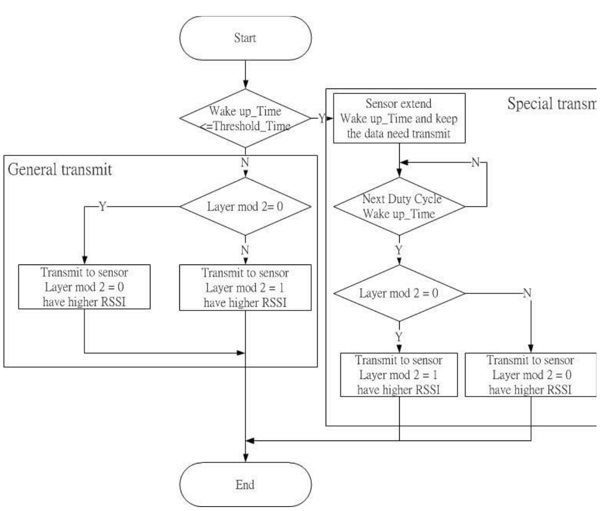

Figure16. Flow chart of Transmit Packet

IV. Comparison and Analysis of Simulation

In this section, "A Concentric-based Sleep Scheduling Scheme for Wireless Sensor Networks" proposed above will be programmed and stimulated in C++ language and compared with S-MAC, Energy Efficient TDMA Sleep Scheduling (EETSS), and SMED. Analysis of the results will be provided in the following sections to prove the mechanism proposed in this paper is more sufficient than the approaches above.

1. Simulation

Setting and parameters of the environment of wireless sensor network used in the stimulation:

- Range of the network: 200M X 200M
- Number of wireless sensor: 20- 200
- Initial power: 4.8W
- Transmit power: 60 mW
- Receive power: 30 mW
- Idle mode power: 30 mW
- Sleep mode power: 0.003 mW
- Transition time: 2.45 ms
- Transmission range: 50 m
- Transmission cycle: 10 seconds
- Threshold_Time: 3ms
- Duty cycle: 30s

2. Analysis and Comparison of The Results

At first, we use 100 sensors and run 300 rounds in the same network area. The stimulating shows as figure.

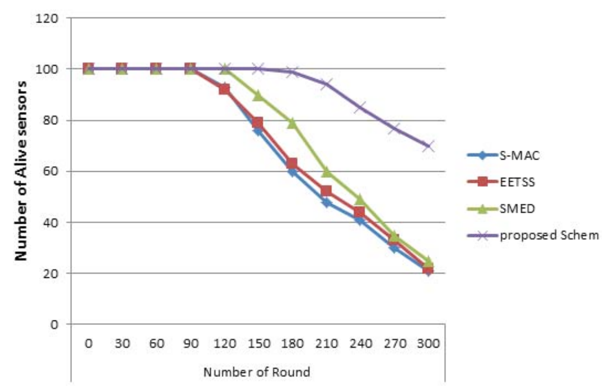

Figure17. Comparison between number of alive sensors.

In figure 17 shows comparison between number of alive sensors. We can observe the power consumption situation of sensors. In S-MAC, sensors not considering the needs of the network to send a message, which would make the area a long idle and cost more energy. In EETSS and SMED, sensors close centers will need more wake-up time to communicate, that cost more energy than our mechanism. The scheme we proposed can balance the duty and energy cost around network area, so we can prolong the time of sensors die.

In figure 18 show comparison between number of alive sensors near sink. We observe 40 sensors much near sink, and we can see that the closer to the sink sensors required heavier work burden in S-MAC, EETSS, and SMED. In this result, we can see that the scheme we proposed can effective reduce the hot spot issue because we consider the work load of sensors near sink, balance the work and the sleep time of each sensor, and the result show that our scheme has greater performance than other scheme in prolong lifetime and hot spot issue.

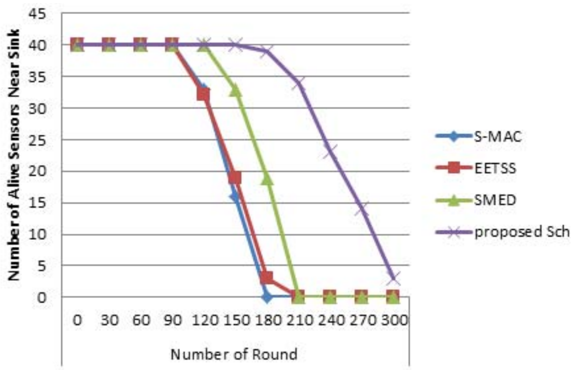

Figure18. Comparison between number of alive sensors near sink

Then we compare the packet transmission delays in the same range network with a different number of sensors.

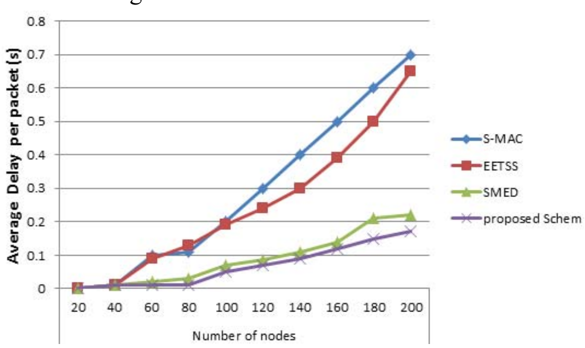

Figure19. Comparison between average delay per packet

Figure 19 shows the comparison between average delay per packet. We can see that S-MAC has the worst performance on packet delay, because the sensor's sleep time did not consider the case of long-distance transmission, network easier be divided into a number of different duty cycle areas with the larger number of sensors, once the multi-hop transmission more times, the situation is more serious delay. In EETSS, arrangements of duty cycle need very tight, with the network's topology deeper and it's more difficult to fit sensor's duty cycle in route, and easy to cause delay. SMED and our scheme result are very close, it's because we both consider the situation of delay in route, but our scheme is better because we reduce the transmission path disruption may happen between different duty cycle of sensor.

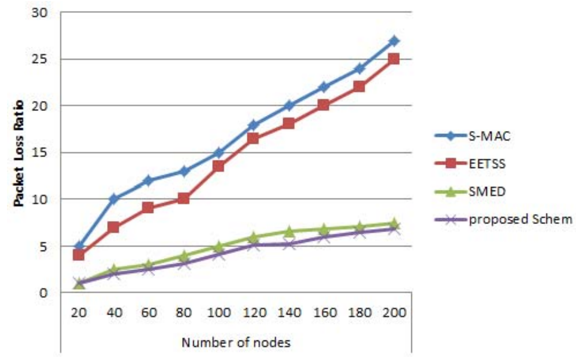

Figure20. Comparison between packet loss ratio

Figure 20 shows the comparison between packet loss ratio, we define packet loss ratio: Total number packets not received at the BS/ Total number packets send by all the sensor nodes. We can see the result S-MAC and EETSS are not considered as the sleep cycle transmission path, so there is a higher loss rate. SMED and our scheme considerate the needs of the sensor transmission, therefore, packet loss rate dropped significantly. But in SMED, two sensors is still may be in the case of different duty cycles, and loss packets, so slightly worse than the scheme we propose.

From four sets of stimulating experiment, it is apparent that "A Concentric-based Sleep Scheduling Scheme for Wireless Sensor Networks" in this paper is a sufficient sleep scheduling scheme which can save energy, expand lifetime, reducing packet transmission delay and loss ratio of the wireless sensor network. Finally, the purpose of the research is achieved.

V. Conclusion and Future Work

In this paper, we propose an efficient sleep scheduling scheme. In our scheme we divide the network into multiple concentric areas, and sensors in different even or odd number concentric areas can work in rotation.

From the result of the stimulation, we can show that the performance of number of alive sensors as well as number of alive sensors near sink is greater than other scheme. The packet delay and packet loss ratio is reducing when the density of network sensors addition. In summary, with our scheme, we can balance power consumption of sensors, extend the lifetime of the network, and can also deduce hot spot issue.

In future work, we should add an efficient sensors deployment scheme to avoid collision when we build route. And how to reduce the energy cost when we construct concentric areas and route also need we to discussion further.

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