End-To-End Delay Optimization in Wireless Sensor Network (WSN)

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*Abstract— **In this paper, we are interested in optimizing the delay of event-driven wireless sensor networks, for which events does not occur frequently. In such systems, most of the energy is consumed when the radios are on, waiting for an arrival to occur. Sleep-wake scheduling is an effective mechanism to prolong the lifetime of this energy constrained wireless sensor networks by optimization of the delay in the network but this scheme could result in substantial delays because a transmitting node needs to wait for its next-hop relay node to wake up. An attempt has been made to reduce these delays by developing new method of packet forwarding schemes, where each nod opportunistically forwards a packet to the its neighboring node that wakes up among multiple candidate nodes. In this paper, the focus is to study how to optimize the packet forwarding schemes by optimization of the expected packet-delivery delays from the sensor nodes to the sink. Based on optimized delay scheme result, we then provide a solution to the central system about how to optimally control the system parameters of the sleep-wake scheduling protocol and the packet forwarding protocol to maximize the network lifetime, subject to a constraint on the expected end-to-end packet-delivery delay. Our numerical results indicate that the proposed solution can outperform prior heuristic solutions in the literature, especially under the practical scenarios where there are obstructions, e.g., a lake or a mountain, in the area of wireless sensor networks*.*

Keywords- Sleep wake scheduling; Sensor network; End-to-End delay

I. INTRODUCTION

In the present era of network communication, the wireless sensor network due to their unique features and capability can remotely sense the environment very efficiently and effectively. These wireless sensor network systems are often deployed in remote or hard to reach areas. Hence, it is critical that such networks might be unattended for long durations. Therefore, extending network lifetime through the efficient use of energy has been a key issue in the development of wireless sensor networks. In this paper, we will focus on event driven asynchronous sensor networks, where occurrences of events are rare. This is an important class of sensor networks and has many applications such as environmental monitoring, intrusion detection, etc. In such systems, there are four main sources of energy consumption namely; energy required keeping the communication radios on; energy required for the transmission and reception of control packets; energy required to keep sensors on; and energy required for actual data transmission and reception. The fraction of total energy consumption for actual data transmission and reception is relatively small in these systems, because events occur so rarely. The energy required to sense events is usually a constant and cannot be controlled. Hence, the energy expended to keep the communication system on (for listening to the medium and for control packets) is the dominant component of energy consumption, which can be controlled to extend the network lifetime. Thus, sleep-wake scheduling becomes an effective mechanism to prolong the lifetime of energy constrained event driven sensor networks. By putting nodes to sleep when there are no events, the energy consumption of the sensor nodes can be significantly reduced.

Different kinds of sleep-wake scheduling protocols for wireless sensor network have been proposed in the available literature. However, various synchronized sleep-wake scheduling protocols have been proposed in [1]. In these protocols, sensor nodes periodically exchange and

synchronize the available information with neighboring nodes. However, such synchronization procedures leads to additional communication overhead and furthermore consume a considerable amount of energy. On demand sleep-wake scheduling protocols have been proposed in [2, 3], where nodes turn off most of their circuitry and always interested in asynchronous sleep wake scheduling protocols such as those proposed in [4], [5]. In these protocols, the sleep wake schedule at each node is independent of that of other nodes, and thus the nodes do not require either a synchronization procedure or a secondary low-power receiver. However, because it is not practical for each node to have complete knowledge of the sleep wake schedule of other nodes, it incurs additional delays along the path to the sink because each node needs to wait for its next-hop node to wake up before it can transmit. This delay could be unacceptable for delay-sensitive applications, such as fire detection or tsunami alarm, which require that the event reporting delay be small. Prior work in the literature has proposed the use of packet forwarding schemes to reduce this event reporting delay [6,7].

II.   PROBLEM DEFINITION

The usage of wireless sensor networks gives rise to several factors that affect the efficiency of the entire system. Some of the factors are - Limited bandwidth, Limited battery power, Energy consumption, Fault tolerance, Self organization, scalability and reliability. The main objective of this paper is to focus on one of the fundamental resources: "energy consumed during data transmission". The sensor nodes have to transmit the data to the sink node each time on occurrence of an event. Since they are generally battery-powered, usage of large amount of energy during data transmission eventually decreases the life time of the sensor nodes. This paper aims at decreasing the energy consumption by implementing multihop routing at the shortest path between the source and destination so that the delay between nodes can be minimized and in turn saves the energy consumption significantly.

Recent advances in wireless sensor networks have resulted in a unique capability to remotely sense the environment. These systems are often deployed in remote or hard-to reach areas. Hence, it is critical that such networks operate unattended for long durations. Therefore, extending network lifetime through the efficient use of energy has been a key issue in the development of wireless sensor networks. Under traditional packet forwarding schemes, every node has one designated next-hop relaying node in the neighborhood, and it has to wait for the next-hop node to wake up when it needs to forward a packet. In contrast, under proposed packet-forwarding schemes, each node has

turn on a secondary low powered receiver to listen to wake up calls from neighboring nodes when there is a need for relaying packets. However, this on demand sleep wake scheduling can significantly increase the cost of sensor motes due to the additional receiver. In this work, we are

multiple next-hop relaying nodes in a candidate set named as forwarding set 'a'. A sending node can forward the packet to the first node that wakes up in the forwarding set. The advantage of proposed packet forwarding scheme in sensor networks with asynchronous sleep-wake scheduling. Assume that each node wakes up independently according to a Poisson process with a common rate λ, i.e., the intervals between every two successive wake-up events of any given node and exponentially distributed with mean $1/\lambda$.

Although proposed scheme clearly reduces the event-reporting delay, it leads to a number of challenging control and optimization problems. The first challenge is for each node to determine its proposed forwarding policy to minimize the end-to-end packet delivery delay. Therefore, each individual node must choose its proposed forwarding policy (e.g., the forwarding set) distributively, with minimal knowledge of the global network topology. The existing packet forwarding schemes in the literature [6,7] address this problem using geographical information. However, these heuristic solutions do not minimize the end-to-end delay. The second challenge stems from the fact that good performance cannot be obtained by studying the proposed forwarding policy in isolation. Rather, it should be jointly controlled with the parameters of sleep-wake scheduling (e.g., the wake-up rate of each node). Note that the latter will directly impact both network lifetime and the packet-delivery delay. Hence, to optimally tradeoff network lifetime and delay, both the wakeup rates and the proposed packet-forwarding policy should be jointly controlled. However, such interactions have not been systematically studied in the literature [6,7].

Before we present the details of our problem formulation and the solution, we make a note regarding when the proposed packet forwarding scheme protocols and the above optimization algorithms are applied. We can view the lifetime of an event-driven sensor networks as consisting of two phases: the configuration phase and the operation phase. When nodes are deployed, the configuration phase begins, during which nodes optimize the control parameters of the proposed forwarding policy and their wake-up rates. It is during this phase that the optimization algorithms discussed above will be executed. In this phase, sensor nodes do not even need to follow asynchronous sleep-wake patterns. After the configuration

phase, the operation phase follows. In the operation phase, each node alternates between two phases, i.e., the sleeping phase and the event reporting phase. In the sleeping phase, each node simply follows the sleep wake pattern determined in the configuration phase, waiting for events to occur. Note that since we are interested in asynchronous using the control parameters chosen during the configuration phase. Note that the configuration phase only needs to be executed once because we assume that the fraction of energy consumed due to the transmission of data is negligible. However, if this is not the case, the transmission energy will play a bigger role in reducing the residual energy at each node in the network. In this case, as long as the fraction of energy consumed due to data transmission is still small (but not negligible), the practical approach would be for the sink to initiate a new configuration phase after a long time has passed.

The paper is organized in subsequent section as follows. The second section, we describe the wireless sensor network model and introduce the delay optimization problem that we intend to solve. In third section, we develop a distributed algorithm that solves the delay optimization problem. In fourth section, we provide simulation results that illustrate the performance of our proposed algorithm compared to other heuristic algorithms in the literature. Ease of Use

III. WIRELESS SENSOR NETWORK (WSN) MODEL

As discussed in the earlier section, the proposed model will focus on event-driven asynchronous sensor networks, where events occur rarely. This is an important class of sensor networks and has many applications such as environmental monitoring, intrusion detection, etc.

In such systems, there are four main sources of energy consumption:

- energy required to keep the communication radios on;
- energy required for the transmission and reception of control packets;
- energy required to keep sensors on; and
- energy required for actual data transmission and reception.

The fraction of total energy consumption for actual data transmission and reception is relatively small in these systems, because events occur so rarely. The energy required to sense events is usually a constant and cannot be controlled. Hence, the energy expended to keep the communication system on (for listening to the medium and for control packets) is the dominant component of energy consumption, which can be controlled to extend the network lifetime. Thus, sleep-wake scheduling becomes an

sleep wake scheduling protocols, the sensor nodes do not exchange synchronization messages in this sleeping phase. Finally, when an event occurs, the information needs to be passed on to the sink as soon as possible, which becomes the event reporting phase. It is in this event reporting phase when the proposed forwarding protocol is actually applied, effective mechanism to prolong the lifetime of energy constrained event-driven sensor networks. By putting nodes to sleep when there are no events, the energy consumption of the sensor nodes can be significantly reduced.

In this paper, the various protocols have been implemented namely; HTTP, FTP and TCP. The routing schemes developed will delivers a message to any one node amongst group of nodes, typically the one nearest to the source and forward the packet to that node immediately, which is very novel way to reduce the end-to-end delay significantly. We define the end-to-end delay as the delay from the time when an event occurs, to the time when the first packet due to this event is received at the sink. We motivate this performance objective as follows: for applications where each event only generates one packet, the above definition clearly captures the delay of reporting the event information. For those applications where each event may generate multiple packets, we argue that the event reporting delay is still dominated by the delay of the first packet. This is the case because once the first packet goes through, the sensor nodes along the path can stay awake for a while. Hence, subsequent packets do not need to incur the wake-up delay at each hop, and thus the end-to-end delay for the subsequent packets is much smaller than that of the first packet. The proposed network model system architecture described in detail in the following section which consists of two phases namely; configuration phase and operation phase.

A. Configuration Phase

As nodes are deployed, the configuration phase begins, during which, nodes optimize the control parameters of the proposed forwarding policy and their wake-up rates. It is during this phase that the optimization algorithms discussed above will be executed. In this phase, sensor nodes do not even need to follow asynchronous sleep-wake patterns.

B. Orientation Phase

In this phase, each node alternates between two sub-phases, i.e., the sleeping sub-phase and the event-reporting sub-phase. In the sleeping sub-phase, each node simply follows the sleep wake pattern determined in the configuration phase, waiting for events to occur. Note that since we are interested in asynchronous sleep-wake scheduling protocols, the sensor nodes do not exchange

synchronization messages in this sleeping sub-phase. Finally, when an event occurs, the information needs to be passed on to the sink as soon as possible, which becomes the event-reporting sub-phase. It is in this event reporting sub-phase when the proposed forwarding protocol is

randomly in the area that is to be monitored. The number of nodes that are to be deployed is determined by the size of the area that is to be monitored.
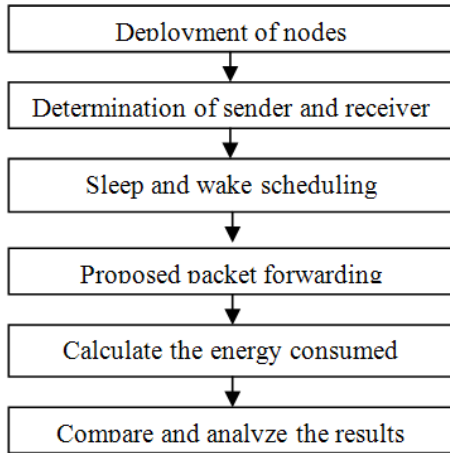

Figure 1.   Flowchart of System Architecture.

A.   System Description

The proposed scheme is divided into the following three different modules:

- Deployment of nodes
- Sleep and wake scheduling
- Proposed packet forwarding

1)   Deployment of Nodes: We consider a wireless sensor network with N nodes. Let N denote the set of all nodes in the network. Each sensor node is in charge of both detecting events and relaying packets. If a node detects an event, the node packs the event information into a packet, and delivers the packet to a sink '*s*' via multihop relaying. The master node collecting all information gathered by the sensors is located at the center of the network. Assume that all nodes have a common maximum radio range 'r' and are equipped with omni directional antennas. Nodes can choose an arbitrary transmit power level for each data transmission, provided that their transmission range does not exceed 'r'. Also, network topologies are considered such that for any sensor at least one path connecting the sensor to the sink. The information sensed by a network node is organized into data units of fixed size that can be

actually applied, using the control parameters chosen during the configuration phase.

IV.   SYSTEM ARCHITECTURE

Figure 1 describes the flow diagram of the system architecture. It starts with the deployment of sensor nodes stored at the sensor in a buffer; the buffer is modeled as a First in First Out (FIFO) queue.

2)   Sleep and wake scheduling: For ease of exposition, in this basic protocol we assume that there is a single source that sends out event-reporting packets to the sink.

Proposed Packet Forwarding Scheme: Under proposed packet forwarding schemes, each node has multiple next-hop relaying nodes in a candidate set (we call this set a forwarding set). A sending node can forward the packet to the first node that wakes up in the forwarding set. The first challenge is for each node to determine its anycast forwarding policy to minimize the end-to-end packet delivery delay.

V.   RESULTS AND DISCUSSIONS

The end-to-end delay has been simulated using NS2, the comparison between Existing scheme and proposed scheme has been discussed in the following section. The figure 2 shows node delay for proposed scheme and figure 3 shows node delay for Existing scheme, the node delay in proposed scheme has been reduced significantly in the proposed scheme when system is operating for 5 ms node mobility.
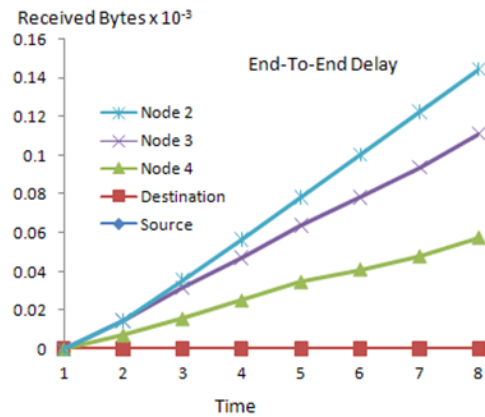

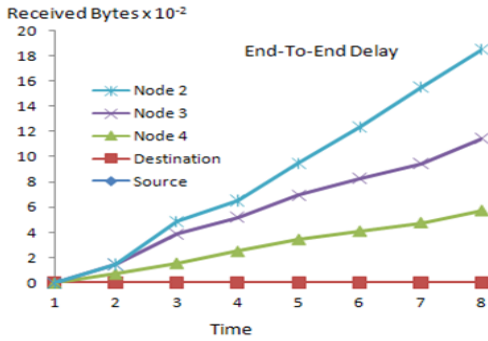Figure 2.   Node Delay for Proposed Scheme.

Figure 3.   Node Delay for Existing Scheme.

VI.   CONCLUSIONS

Following conclusions are made from the proposed scheme used in this paper are:

- Proposed scheme has been developed to reduce the event-reporting delay and to prolong the lifetime of wireless sensor networks employing asynchronous sleep-wake scheduling.
- Proposed scheme also resulted in to maximize the network lifetime subject to a upper limit on the expected end-to-end delay.
- Our numerical results suggest that the proposed scheme can substantially outperform prior heuristic solutions in the literature under practical scenarios

where there are obstructions in the coverage area of the wireless sensor network.

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