Delay-Efficient Approaches for Sleep Scheduling in Wireless Sensor Networks

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Abstract
Wireless sensor networks (WSN) have recently used in many applications like surveillance, military applications, etc. In such applications, the sensor nodes are expected to be work long period of time without recharging their batteries. To extend the network lifetime, some sleep scheduling techniques always used, which may cause communication delay in large scale WSNs. In this paper, we present the challenges in the design of delay efficient sleep scheduling, comparison of different approaches in terms of performance metrics and future outlook of communication delay in WSN.

Keywords:
sleep scheduling, wake-up pattern

1. Introduction

In wireless sensor network, large numbers of sensor nodes are deployed in a wide range of areas to detect and report mission critical information to the end-users. When a critical event occurs such as gas leak in factory or fire in the forest is detected by a sensor node, an alarm needs to be broadcast to the other nodes as soon as possible. Sleep scheduling method is always used during the monitoring process to reduce the energy consumption so that the sensor nodes for event monitoring in wireless sensor networks are expected to work for a long time without recharging their batteries. In sleep scheduling, sender nodes should wait until receiver nodes are active and ready to receive the message. Sleep scheduling should increase the network life time but it could cause transmission delay. Whenever the network scale increases, the broadcasting delays also increase. So, delay efficient sleep scheduling methods are needs to be designed to provide low broadcasting delay from any node in the WSN.
Most of sleep scheduling methods in [1],[2],[3] focus to minimize the energy consumption. To minimize the broadcasting delay in WSN, the time wasted for waiting during the broadcasting needs to be minimized. So there is a need for balance both energy consumption and broadcasting delay in wireless sensor network. The destination node wakes up immediately when the source nodes obtain the broadcasting packets. Here, the broadcasting delay is reduced.

This paper is organized as follows. Section 2 includes a discussion on key concept of sleep scheduling, wake-up pattern, level-by-level offset and MAC protocol; section 3 includes broadcasting delay efficiency in wireless sensor networks and its performance metrics; section 4 gives the future research directions and section 5 gives the conclusion on this paper.

2. KEY CONCEPTS

A. Sleep Scheduling

Wireless sensor networking is always worked with sleep scheduling which is used to reduce the energy consumption. Sleep scheduling is probably the most efficient mechanism to increase the lifetime of energy constrained sensor networks. Sleep scheduling can be classified into two types such as, synchronized sleep wake scheduling protocol and asynchronized sleep wake scheduling protocol.
In synchronized sleep wake scheduling, each node knows exactly when its neighbour nodes will wake up. Then each node in wireless sensor network needs to exchange synchronization message with other nodes. It causes the additional communication overhead.
In asynchronized sleep wake scheduling, each sensor nodes wake-up independently. Each sensor node can only estimate when its neighbour nodes will wake up. It could result in a large delay than in the synchronized scheduling.

B. Wake-up Pattern

In sleep scheduling, most of the time nodes stay in low-power or sleep modes. But periodically waking up to check or monitor for activity. This increased longevity, however, comes at the cost of increased message delivery latency since a forwarding node has to wait until its next-hop neighbour awakens and is ready to receive the message. Current wake-up methods can be divided into two main categories:

1) Scheduled wakeups: In this class, the nodes follow possibly random wakeup patterns. Time synchronization among the sensor nodes in the wireless sensor network is generally assumed. However, asynchronous wakeup mechanisms which do not require

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synchronization among the different nodes are also categorized in this class. Although asynchronous methods are simpler to implement, they are not as efficient as synchronous schemes, and in the worst case their guaranteed delay can be very long.

2) Wakeup on-demand: It is assumed that the nodes can be notified and awakened at any point of time and then a message is sent to the node. This is usually implemented by employing two wireless interfaces. The first radio is used for data communication and is triggered by the second ultra low-power radio which is used only for paging and signalling.

C. Level-by-Level Offset

All nodes have a periodic receive-transmit sleep scheduling with *level-by-level offset*, which means that all nodes wake up when their source nodes have just gotten data packets, and go to sleep as soon as possible they transmit packets to their neighbour nodes. The idea of *level-by-level offset schedule* can achieve much lower transmission delay in one traffic direction but it is not efficient when bidirectional delay guarantee is required.

D. MAC Protocol

We expect sensor network to be deployed in ad-hoc fashion, with individual nodes remaining largely inactive for long periods of time but then becoming suddenly active when something is detected. These characteristics of sensor network and application motivate MAC that is different from traditional wireless MAC such as IEEE 802.11. Energy consumption and self configuration are primary goals.

3. Comparative Study

This section includes a study on some of the scheduling algorithm that have included less energy consumption as well as less broadcasting delay.

E. An Adaptive Energy Efficient and Low Latency MAC

In many sensors network applications the major traffic pattern consists of data collected from several sensor nodes to a center node through a unidirectional tree. In this paper they proposed a data prediction mechanism and the use of more-to-send packets in order to avoid channel contention and collisions.

Nodes which are in sleep mode that are out of the hearing range of both the sender and the receiver are unaware of ongoing data transmissions, and therefore go to sleep until the next cycle. The data forwarding process will then stop at the node whose next hop towards the center is in the out of range because it is in deactivation mode. Packets will then have to be queued until the next active period, which leads communication latency.

There are three main communication patterns in sensor network applications. The first involves local data exchange among nearby sensor nodes. The second involves the dispatch of control packets and response packets from the center to sensor nodes. The third traffic pattern in WSN is data gathering from sensor nodes to sink or center node. Routes may change during data delivery, but assume that sensor nodes are fixed, so that a data gathering tree remains stable for a reasonable length of time. Flows in the data gathering tree are unidirectional from sensor nodes to center node. All nodes except the center node will forward any packets.

Dynamic Medium Access Control is proposed to deliver data along the data gathering tree, aiming at both energy efficiency and low latency. An interval of the duty cycle is divided into receiving, sending and sleep periods. In receiving state, a node will try to receive a packet and send an ACK packet back to the sender. In the sending state, a node will try to send a packet to its neighbour node and receive an ACK packet.

In sleep state, nodes will enter into deactivation mode to save energy. The receiving and sending periods have the same length of μ which is enough for one packet of information transmission and reception. Depending on its depth d in the data gathering tree, a node skews its wake-up scheme dμ ahead from the schedule of the center node. In this structure, data delivery can only be done in unidirection towards the root node.

Data prediction is employed to solve the problem when each single source has low traffic rate but the aggregated rate at an intermediate node is larger than what the basic duty cycle can handle. The interference between nodes with different parents could cause a traffic flow be interrupted because the nodes on the multihop path may not be aware of the interference. The use of an More To Send packet is proposed to command nodes on the multihop path to remain active when a node fails to send a packet to its parent due to interference. These increase the energy consumption.

F. Delay Efficient Sleep Scheduling

This paper addressed the important problem of minimizing communication delay while providing energy efficient periodic sleep cycles for nodes in wireless sensor networks. The objective is to reduce the delay given the duty cycling requirement. For the single wake up schedule case, where each sensor can wake up at exactly one of the k slots, it provided by graph-theoretic problem formulations for arbitrary all-to-all as well as weighted communication patterns. Both problems are NP-hard. Using this technique, they proposed algorithms with provable guarantees on tree, grid and arbitrary graphs.

1) Techniques to compute good lower bounds on the optimal delay diameter for an arbitrary graph. 2) Good distributed heuristics for the DESS problem. 3) In-depth

analysis and algorithms for the weighted communication average delay problem. 4) Incorporation of local interference constraints similar to TDMA scheduling problems to handle moderate to high traffic scenarios. 5) Implementation and validation of delay efficient schedules in real-world sensor networks.

G. Minimum Latency Broadcast Scheduling

This paper illustrate a practice of pipeline process to maximize the parallelization of all possible interference free relays in the broadcasting of wireless sensor networks, in order to optimize the end-to-end delay performance. Broadcasting the information is one of the basic communications in WSNs. Existing delay-sensitive broadcasting schemes based on counting the hop distance to the source. In the duty cycle system, such a block can cause the relay to miss the wake-up time of the successor node which leads to the extra delay.

The contributions of this are threefold: 1) Clarify the minimum latency problem of broadcasting in both the round-based synchronous system and the asynchronous duty cycle system by a color selection scheme [9][10]. 2) To reduce the cost of the heuristic method while still achieve the above optimization target, it provide a non-heuristic solution for the well-known greedy color scheme in both the synchronous and asynchronous systems. 3) Develop a custom simulator to testify that the optimization achieved in the greedy color scheme is very close to our ultimate optimization target, in either the synchronous or asynchronous system.

In the future work, it will focus on a localized color scheme and its selection to provide a more reliable and scalable solution. Introducing the delay measurement to the color labelling process may help to further improve the broadcast performance. The further optimization can be conducted with other constraints, such as energy saving, traffic throughput control, etc. The duty cycle network model can be extended to other delay-sensitive communications, such as social networks.

H. Energy and Latency Control in Low Duty Cycle

Several MAC protocols such as SMAC and TMAC have exploited scheduled sleep/wakeup cycles to reduce energy in sensor networks. Most of the protocols have assumed all nodes in the network were configured to follow the same schedule, or have assumed border nodes would follow multiple schedules.

This paper develops two new algorithms to control and exploit the presence of multiple schedules to reduce energy consumption and latency. The first one is the global schedule algorithm. GSA is a fully distributed algorithm that allows a large network to converge on a single global schedule to conserve energy. Secondly, we demonstrate that strict schedules incur a latency penalty in a multi-hop network when packets must wait for the next schedule for transmission. To reduce latency in multi-hop paths it develop the fast path algorithm [11][12]. FPA provides fast data forwarding paths by adding additional wake-up periods on the nodes along paths from sources to sinks.

Fast paths can be very important when less transmission delay is required, as in monitoring the applications. Although they implement those two algorithms in S-MAC, the general approaches are applicable to other MAC protocols with a sleep/wakeup schedule, such as T-MAC and Zigbee. Global schedule algorithm allows all nodes to converge on a single global schedule to conserve energy, while fast paths allocate additional slots to avoid schedule misses and reduce latency. This evaluates the energy savings of our global schedule algorithm in a two schedule network and latency savings.

I. Delay Constrained Minimum Energy Broadcast

This paper identifies the problem of delay constrained energy-efficient broadcast in cooperative multihop wireless networks. This important problem is o (log (n)). It derives approximation results and an analytical lower-bound for this problem.

This paper breaks this NP hard problem into three parts: ordering, scheduling and power control. When the ordering is given, the joint scheduling and power-control problem can be solved in polynomial time by a novel algorithm that combines dynamic programming and linear programming to yield the less energy broadcast for a given delay constraint, This algorithm used in conjunction with an ordering derived heuristically using the Dijkstra's shortest path algorithm yields near-optimal performance in typical settings.

There are three main approaches for cooperative communications in networks. One is using coherent signal synchronization, in which a set of transmitters synchronize their transmissions at the signal level when transmitting to a single receiver [1].

The second approach is energy accumulation [2][3][4], in which a receiver can recover the original packet so long as the total received energy from multiple sources or successive transmissions exceeds a given threshold. It has been shown that one can achieve significant saving in energy and/or transmission time when using an energy accumulation protocol, compared to traditional protocols [2][5]. If energy accumulation is achieved by transmitting the exact same packet from different relays or through successive retransmissions, the scheme is shown to achieve capacity in an asymptotically wideband regime [2].

The third approach is mutual information accumulation, which can be achieved using rateless codes [6]. The two schemes have been shown to be equivalent at low signal-to-noise ratios [6]. It has developed by an analytical lower bound and provable approximation results. Another key algorithmic contribution has been to show a polynomial time algorithm that can solve the problem optimally for a fixed transmission ordering.

This paper focused on the static problem with full information, which allows for centralized decision making. In the future, it would like to explore distributed solutions to this problem which would be particularly suitable for more dynamic settings. Evaluating the proposed algorithms under more realistic settings would certainly help in moving this work towards practice.

4. FUTURE RESEARCH DIRECTIONS

It is known that the alarm could be originated by any node which detects a critical event in the WSN. To essentially reduce the broadcasting delay, the proposed scheduling method includes two phases: Any node which detects a critical event sends an alarm packet to the center node along a predetermined path according to level-by- level offset schedule. The center node broadcasts the alarm packet to the entire network according to level-by-level offset schedule.

The traffic paths define the traffic path from nodes to centre node as uplink and define the traffic path from the center node to other nodes as downlink, respectively. Each node needs to wake up properly for both of the two traffics. Therefore, the proposed scheduling scheme [13] should contain two parts: 1) Establish the two traffic paths in the WSN, 2) Calculate the wake-up parameters for all nodes to handle all possible traffics.

To minimize the broadcast delay, BFS tree for the uplink traffic and CCDS for the downlink traffic are established respectively. The upper bound of the broadcasting delay D is the maximum hop of nodes to the center node, and is the length of duty cycle; the unit is the size of time slot.

After all nodes get the traffic paths, sending channels and receiving channels with the BFS and CCDS, the proposed wake-up pattern is needed for sensor nodes to wake-up and receive alarm packet to achieve the minimum delay for both of the two traffic paths. There are two traffic paths for the alarm dissemination, and sensor nodes take two level-by-level offset schedules for the traffic paths.

The two level-by-levels offset schedules: 1) Sensor nodes on paths in the BFS wake up level-by-level according to their hop distances to the center node. 2) After the center node wakes up, the nodes in the CCDS will go on to wake up level- by-level according to their hop distances in the CCDS.

This combination of the sleep scheduling in wireless sensor networks with level-by-level offset can be reduce the energy consumption and communication delay. This method also avoid the collision during the broadcasting the alarm in wireless sensor networks.

5. CONCLUSION

Recently several sleep scheduling for the wireless sensor network have been proposed by the researchers. However, no one consider the communication latency.

Dynamic Medium Access Control is designed to solve the interruption problem and allow continuous packet forwarding by giving the sleep schedule of a node an offset that depends upon its depth of the data gathering trees. It also adjusts the duty cycles adaptively according to the traffic load in the network.

Techniques in delay efficient sleep scheduling it can choosing multiple wake up slots for each sensor. So it should minimize the communication latency. Energy & latency control in low duty cycle MAC protocol reduce latency in multi hop paths. GSA is a fully distributed algorithm that allows a large network to converge on a single global schedule to conserve energy.

The Code Division Multiple Access (CDMA) scheme also offers collision free access to the medium. However, the high computational complexity is the limitation in the lower energy consumption needs of the sensor network.

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