ISSN 2229-5518

Decentralized Time Slot Allocation Protocol for mobile Wireless Sensor Networks

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Abstract— In Data-Intensive Applications, Wireless Sensor networks are used to transmit the data's that has been generated within an application. While transmission, the network load is generated where there would be excessive packet collisions causing packet losses and retransmission. In order to address this issue, we introduce a Decentralized Time Slot Scheduling access scheme that reduces high data loss in the networks and also handles some mobility. Our approach minimizes transmission collisions by assigning time slot scheduling in virtual grids employed.

Index Terms— Wireless sensor networks, Data-Intensive Applications, Access Scheduling

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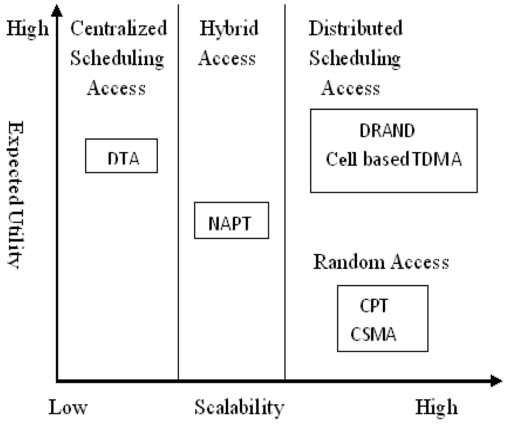
1 INTRODUCTION

SENSOR networks are being deployed for a variety of applications, including habitat monitoring, target tracking, etc., There are some requirements that are common for Data-Intensive Applications(DIAs) Wireless sensor networks (WSNs), perform poorly when high bandwidth and stringent delay constraints is needed. As an example for a DIA that considers WSN can be taken as Structural Health Monitoring (SHM) [5]. This system is that to monitor the civil and military structures integrity. Here Wireless sensors observe excitations around a surveillance structure, then data is gathered and reported sensed data periodically to the base station (BS). Another example of a DIA is the near-continuous monitoring of heat exchangers in a nuclear power plant. It would generate considerable network load in a short period of time. This would lead to collisions between packets which can be considerable obstacle to achieve the required throughput and delay in such an application. Due to increases data load, we can observe severe degradation in network performance. Due to this frequent collisions and retransmissions, packet success ratio drops resulting in the increased time delay to reach the sink and an increase in the overall energy consumption in the WSN. The performance of traditional WSNs becomes unacceptable, after a certain load threshold. And also mobile platforms can be included in Wireless Sensor networks, [1], [2], [8]. To acquire and process data for applications such as surveillance tracking, environmental monitoring in highly sensitive areas, wireless sensor devices can be deployed in conjunction to the stationary nodes.

Wireless channel access methods for sensor networks can be classified into two categories: random access and scheduling access. In random access method, even high-rate wireless networks such as IEEE 802.11 impact data-intensive multimedia applications [10] using best-effort service which cause packet loss, delay and jitter. These problems are worst in low-rate wireless sensor networks such as IEEE 802.15.4 [6]. A recent study [5] reported that successful packet delivery ratio (PDR) in 802.15.4 network can drop from 95 to 55 percent when the load increases from 1 to 10 packets/sec. It is to be noted that it is common for Data-intensive Sensor Networks to generate 6-8 packets/sec, which makes problem more significant. As the PDR drops, sensors may retransmit more in order to increase the likelihood of delivering information resulting in more collisions, energy waste, and reduced network lifetime.

TABLE 1

General Framework of MAC Schemes Classification



Our main focus is the Medium Access Control (MAC) layer fine-grained control is to reduce collisions and energy waste. The popular contention-based MAC scheme adopted in both IEEE 802.11 and IEEE 802.15.4 standards is Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA). As Already reported the performance of this scheme degrades as the load increases. Scheduling-based access methods avoid this problem (for example, Distributed randomized TDMA

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scheduling (DRAND) [12]). Table 1 provides a qualitative summary of various MAC Schemes for WSNs in terms of expected utility and the scalability of access methods in Data-Intensive Networks.

In this paper, we propose a decentralized technique called Cell-based Slot Scheduling protocol (CELSS). This technique maintains graceful performance degradation in DISNs as the data load increases and is designed to be lightweight, overhead-efficient, highly scalable and robust in the presence of mobility.

2 RELATED WORK

In sensor networks, Channels can be classified into scheduling-based and random access categories. Below, we briefly describe some prior work in both categories. For DISNs, which need to support continuous and/or periodic traffic loads, it is more appropriate to employ the scheduling approach to manage channel access. The scheduling approach is mostly adopted into a structure, Time-Division Multiple Access (TDMA).

2.1 Time-Division/Scheduling Scheme

The DTA approach makes use of a set of operations that take transmissions between sensors as input and produce a schedule of transmissions as output by a DTA optimizer. The generated transmission schedule is collision-free due to the knowledge of the collision domains of elementary transmissions. However, the overhead cost of generating the DTA transmission schedule is a concern. This problem can be further magnified in dynamic networks. Sensor MAC (S-MAC) is a static-scheduling-based energy saving protocol that allows neighboring nodes to sleep for long periods and wake up, both in a synchronized fashion, to avoid wasting energy from idle listening, collisions, and retransmissions. Thus, neighbors conserve energy when a node is transmitting. However, S-MAC does not provide an on-demand interaction with the receiver (it uses a static sleep interval). Siva lingam et al. proposed an Energy-Conserving Medium Access Control protocol (EC-MAC) for ad hoc networks. The EC-MAC protocol can only operate in an environment where every sensor hears each other. Lightweight MAC (LMAC) [7] implements a distributed time slot scheduling algorithm for collision-free communications. Time is divided into slots and sensor nodes broadcast information about time slots, which, as they believe, they control. Neighboring sensor nodes will avoid picking up those slots and choose other slots to control. Within its time slot, a sensor node will transmit a message with two parts: control and data. The control part includes sufficient information for neighbors to derive a time slot schedule of local sensors so that transmissions among neighboring sensors will not collide. Sensors must listen to the control parts of their neighbors. Time slots can be reused at distances where interference is small (three hops for instance). With such an algorithm, the goal of collision avoidance is achieved at the price of extra control overhead and listening time. Chatterjea et al. enhanced LMAC with Adaptive, Information-Centric, and Lightweight MAC (AILMAC) [9] that uses captured local data about traffic patterns to modify operations accordingly. While AI-LMAC is adaptive and information-centric, it still shares LMAC’s extra control overhead and faces possible performance deficiency from unexpected burst traffic. Both LMAC and AI-LMAC were designed not with the goal of supporting high data loads, but with the objective of reducing the switching time/cost from sleep mode to transmit mode. Rhee et al. [12] propose a distributed randomized time slot scheduling algorithm, DRAND that is used within a MAC protocol called Zebra-MAC [11] to improve performance in sensor networks by combining the strength of scheduled access during high loads and random access during low loads. The distributed implementation of DRAND allows a sensor to select a time slot, which is distinct from time slots of its two-hop neighboring sensors. This feature reduces data packet collisions. The DRAND algorithm includes two major phases: Neighbor Discovery- Hello and DRAND Slot Assignment. In the neighbor discovery phase, sensors broadcast Hello messages periodically to announce their existence. Next, sensors exchange control messages like Request, Grant, Release, or Reject to determine the time slots of sensors. With this scheme, the message complexity is O (n), where n is the maximum size of a two-hop neighborhood in a wireless network. While DRAND provides reliable data transmissions, some constraints are noted. First, this algorithm is suitable for a wireless network where most nodes do not move. If the topology changes dynamically, the algorithm should be run frequently to ensure delivery reliability.

2.2 Random Access Schemes

Random access techniques implement highly scalable and lightweight distributed medium access control schemes. The IEEE 802.15.4 standard utilizes random contention access using CSMA/CA but it suffers from poor performance in DISNs [5], [6]. Schurgers et al. [3] proposed a contention-based protocol called Sparse Topology and Energy Management (STEM) to save energy. STEM implements a two-radio architecture that allows the data channel to sleep until communication is required. Channel monitoring alleviates collisions and re-transmission.

3 CELSS PROTOCOL

This protocol includes three phases: Cell searching, Transference Frame (TF) Assignment, and Time Slot Scheduling. This protocol is completely decentralized and it either periodically checks the accuracy of time slot assignment or requires the mobile nodes to verify / update their time slots to account for relocation of nodes in a mobile WSN.

3.1 Cell Searching

We designed a CS algorithm for assigning monitoring area to cells. WE assume the cells which are of uniform shapes and sizes which virtually split from the monitoring area. The length of one edge of the any cell is R which is of ranges between 2r and 2.1r, where r is the transmission range of sensors.

In our paper we set the R value as 2.1r and each cell is identified by a unique ID, associated with its location, ie, pair of coordinates (CS_Xi, CS_Yi). CS_Xi and CS_Yi represent the vertical and horizontal coordinates of a cell correspondingly. Every sensor applies the CS algorithm to determine the ID of the cell using its location information.

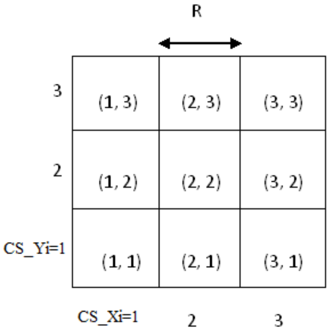

Fig. 1. Virtual cell network

Here, (xi, yi) is the location of Sensor I and (X', Y') defines the area covered by the WSN. If a sensor is located on a border between two cells, this sensor will randomly choose a cell's ID between these two cells. Note that we here introduce a simple cell search method based on a proprietary two-dimension map. The CS algorithm will be modified if the geographical coordinate system changes.

3.2 Transference Frame Assignment

After a sensor locating its virtual cell, it proceeds with TFF assignment. We define a TFF as a group of continuous time slots and its structure repeats to handle sensors' transmit, idle, or receive states. The TFF can be further divided into multiple equal Sub transmission Frames (STFFs) that are orthogonal (Fig 2). The sensor uses the CS result from the first phase to independently assign itself an STFF (either A or B).

As a result, sensors in adjacent cells operate at different STFFs, reducing potential for collisions.

Length of TF = 2 * STFF
= 2 * ([Number of Deployed Sensors / Number of Grids in the network] + α)

3.3 Transference Frame Assignment

After sensors discover their CS and STFF, the next step is to determine a time slot for the transmission state of each sensor. First, each sensor performs neighborhood discovery to prepare for time slots scheduling. For the neighborhood discovery there is a requirement of all sensors to broadcast their information about CS and STFF to one-hop neighbors. In this way, each sensor is aware of its neighbors and maintains a neighbor table which records neighbors' ID, distance/hop count, CS, and STFF. Because the side length of all cells is 2.1r, the maximum distance for a sensor to convey data within a cell is three hops. In other words, the sensor needs two or three broadcast messages to announce it and discover neighbors' presence within a cell if none of the messages is lost. After the time slot allocation schedule is set, sensors run the transmission, receive, or sleep mode in time slots.

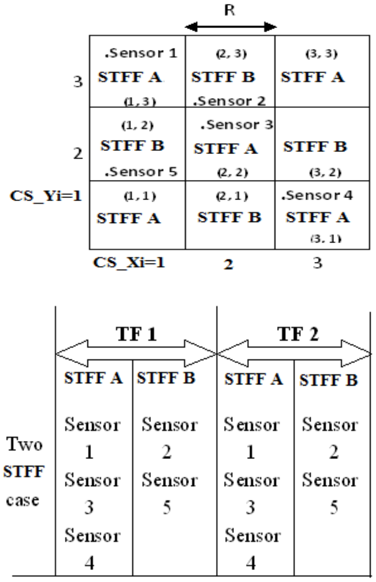

Fig. 2. Network with two STFs configuration.

4 SIMULATION RESULTS

We implemented CELSS in Network Simulator (ns-2) and evaluated transmission efficiency, overhead complexity, latency, impact of changing topology, and scalability. We compare the CELSS protocol with the IEEE 802.15.4 CAP mode (CSMA/CA) [4] and DRAND [12]. We used the comparison with 802.15.4 as a baseline of this study, and DRAND served as an example of an advanced access scheduling approach.

To show transmission efficiency at different levels of network loads, we vary the number of simultaneous senders from 1 (low contention) to 20 (high contention) in the random dense network. These simultaneous senders are selected around the BS for each run. Furthermore, we configure all sensors in the network as simultaneous senders and program them to deliver CBR packets for different data generation rates, i.e., (packet/second/node). We utilize two metrics to demonstrate the transmission efficiency: throughput and success rate (Fig. 3).

We notice that transmission efficiency of the CSMA is unacceptable for high contention scenarios occur near intersections of grid cells, the DRAND protocol is better than the CELSS protocol without the CAIG function. Overall, the performance with NIGS is higher compared to the case of IGS since, with NIGS; the BS is not near the high-contention area. The success rate of CELSS-IGS with 8-20 senders has a concave shape: more data are lost with more than 15 senders. Next, the CELSS protocol with the CAIG function is tested under stringent conditions: 20 simultaneous senders and different data generation rates. Accordingly, it is apparent that the

CAIG function indeed maintains collision resolution around intersections of grid cells, and the complete CELSS protocol matches the DRAND protocol in transmission efficiency under different traffic loads.

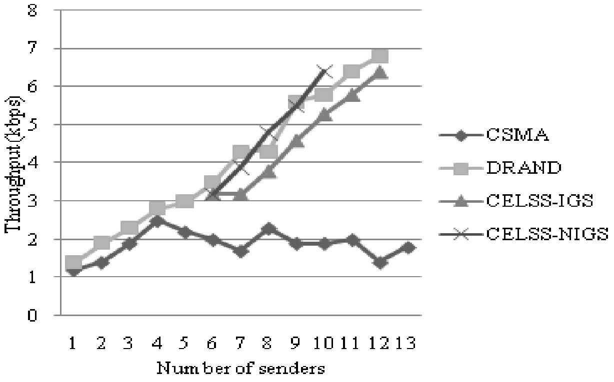

Fig: 3a effect of CAIG on throughput performance

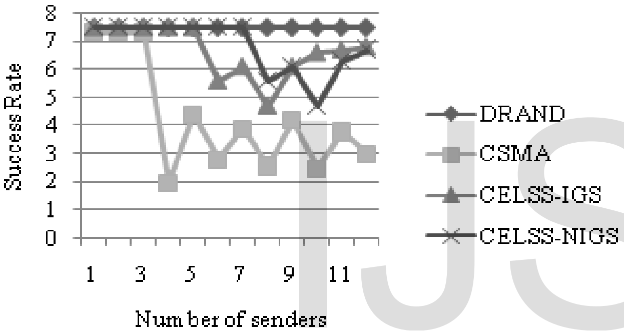

Fig: 3b effect of CAIG on packet success rate performance

5 CONCLUSION

In this paper, we presented a novel grid-based scheduling access technique called CELSS which mitigate the performance degradation in data-intensive mobile sensor networks. According to CELSS protocol, each sensor utilizes the two-hop graph coloring which is to derive a collision-free transmission schedule. The design of a virtual cell network minimizes the protocol complexity and overhead and subsequently improves the scalability. CELSS provides conflict-free time slots assignments in transmission schedules, low control messages overhead and good adaptability in dynamic environments. The results from our analysis and simulations demonstrate the feasibility of our approach in terms of transmission reliability, control overhead, and packet delay. While efficiently eliminating conflicting time slots in transmission schedules, CELSS uses about 33-100 percent of the DRAND overhead in each generation of time slots scheduling. On the other hand, transmission efficiency of the DRAND is satisfactory for all traffic loads. In Figs. 3a and 3b, the CELSS protocol is not equipped with the CAIG function. It shows lower performance compared to the DRAND protocol, but significantly outperforms the CSMA.

Our approach is especially suitable for mobile data-intensive sensor networks with frequently changing topology. In future research, we plan to investigate more sophisticated cooperation between sensors in the process of time slots assignment. The design of a virtual cell network of CELSS is an effective and simple method to cluster local sensors, improving network scalability. However, its operation depends on sensor location awareness. Applying other clustering techniques, we can relax the requirement of location awareness.

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