Fast Data Collection in Tree-Based Wireless Sensor Networks

S.Karthikeyan
ME II Year Department of computer science
KSR College of Engineering
Namakkal, Tamilnadu, India
skarthivi@gmail.com

A.Mumoorthy, Assistant Professor
Department of computer science
KSR College of Engineering
Namakkal, Tamilnadu, India
amummoorthy@gmail.com

***Abstract*—Exploring and evaluating different techniques using real simulation models under multilevel communication paradigm. Consider time scheduling on single frequency channel by minimizing the time slots to complete a converge cast. Scheduling with transmission power control will diminish the effects of interference. The power control helps in reducing the schedule length under single frequency. Scheduling transmissions using multiple frequencies is more efficient than the single frequency. By providing power bounds in the schedule length interference is eliminated. The proposed algorithm can achieve these bounds. The use of multi frequency scheduling is sufficient to eliminate the interference. In this case, the data collection no longer remains limited by the interference. To provide a proper solution we create degree-constrained spanning trees and minimal spanning trees. This will provide a significant improvement in scheduling performance. Finally, in a schedule length we can evaluate the collision in different interference over different channel models.**

INTRODUCTION

Wireless sensor networks (WSNs) have attracted much attention in recent years due to their wide range of applications, such as battlefield, surveillance, biological detection, environmental monitoring, and health habitat. The collection of data from a set of sensors toward a common sink over a tree-based routing topology is fundamental operation in wireless sensor networks. For instance, in safety and mission-critical applications where sensor nodes detect oil/gas leak, structural damage, receive data from all the sensors in a specific deadline. This comes under the category of one-shot data collection. Applications such as permafrost monitoring require periodic and fast data delivery over long periods of time, which falls under the category of continuous data gathering. A WSN is composed of a more number of compact wireless devices, mainly sensor nodes that periodically monitor the phenomena such as, temperature, humidity and transmit raw data to a particular node, for further decision and control. Such operation is referred as data gathering. Previously, some data gathering approaches were proposed for efficient data gathering extending the lifetime of network minimizes the energy consumption in sensor nodes.

Many discrete control applications must cater to hard real-time requirements i.e., sensors must communicate the occurrence of critical events to the controller within a real-time deadline (usually 5-50ms) specified by the control system's design requirements. Messages reached after this deadline are considered lost. In the event of traffic bursts where several sensors may attempt to communicate with the PLC at the same time, messages from all the sensors must reach within the specified deadline. The metric for performance in such systems is then the probability that a message from all the sensors succeeds in being received at the controller within this deadline. Further, for such solutions to be viable, the sensors must last for several years without requiring change of batteries. In this paper we examine the potential for using 802.15.4 based radios for wireless sensing in low-latency hard real-time discrete event control applications.

The operation of several modern-day control systems such as computer numerically controlled (CNC) machines, vehicles, manufacturing robot arrays etc. are based on discrete event control. In a discrete event control system, sensors convey the occurrence of critical events to a controller. The controller then, based on these inputs from the sensors, induces the necessary actuation to control the system. The typical modern-day discrete event control-based CNC machine or a vehicle spans 3-15 meter along its largest dimension (controller to sensors) and houses 50-200 sensors. For a large number of discrete event control-based systems the control loop must cater to hard real-time requirements i.e., the sensing, communication and actuation must occur within a pre-specified deadline.

Given fixed sensing and actuation delays, such deadlines can usually be translated into communication delay deadlines. A message that does not reach its destination before this deadline may cause the machine to go into an error condition that requires its temporary halting or resetting. In machines today, sensors and actuators communicate to the controller via cables and cater to hard real-time communication latencies ranging from 5-50ms depending on the specifics of the machine. Inherent to most discrete event control systems is the unpredictable nature of the traffic i.e., it is hard to predict when, how many, or which sensors will be triggered to communicate at the same time to the controller. This is because the communication is primarily event-driven and it is often impossible to predict the times and nature of occurrence of external events.

In general, traffic bursts are common in most discrete event systems because, i) a single event may lead to several sensors triggering at the same time and ii) more than one event may occur at the same time. In the rest of the paper we shall refer to such event driven bursts as sensor bursts. In the event of a sensor burst, then, messages from all the sensors must reach the controller within the specified deadline since the controller can take appropriate action only upon receiving all the inputs. Failure of receipt of a message from even one sensor may lead to unpredictable failures in the system forcing it into an error recovery state.

A failure will lead to a decreased production throughput and hence significant financial losses. Probability of failure is the most important performance measure in most production systems. Failures in machines such as vehicles may lead to graver consequences including loss of life and property. Not surprisingly, in modern-day machines, sensor-actuator-controller communication is conducted via communication cables. The design of present day machines requires careful de- liberation for routing the cables from various locations within the machine to the controller. Eliminating the cables can not only provide the potential of enabling compact and simple mechanical designs by avoiding cumbersome cabling, but also provide additional benefits in terms of ease of installation and maintenance.

Furthermore, cables are often subject to wear and tear, especially when they are drawn from moving parts within the machine and require frequent maintenance. Each maintenance cycle translates to decreased usage and increased maintenance costs. Elimination of cable wear and tear events translates into less maintenance expenditure and fewer down periods. Further, the possibility of wireless sensors encourages the design of systems with a larger number of sensing points for more efficient control. For most machines, actuators have very high power requirements. The actuators are usually expected to induce mechanical operations such as lifting a part or turning a high speed drill. Actuators thus, cannot be un-tethered and require power-cables to be routed to them. Making the controller-actuator communication wireless does not offer significant advantages since controller-actuator communication cables can be “bundled” up along with the power-lines without significant overhead. Sensors, on the other hand, have modest power requirements, and can be made “completely wireless”, operating only on batteries. Replacing batteries in hundreds of sensors in a machine, however, can be a time-consuming, labor-intensive job. Frequent battery changes resulting in maintenance downtime can offset the gains offered by a wireless sensing system. Considering that the lifetime of typical manufacturing machines or vehicles is 10 years, it will be expected that wireless sensors must operate for at least a few years on batteries before requiring battery replacement.

There are thus, two metrics that completely capture the performance of a communication protocol for low-latency hard real-time discrete event systems: Communication cable-based solutions used in modern-day machines typically provide error rates of 1ppm (1 in 106) or less. A wireless system that replaces an existing system only to become a performance bottleneck will not be accepted as a viable solution. In this paper we ask the question, “Can 802.15.4 based radios be used for wireless sensing in low-latency hard real-time discrete control systems?” Rather than taking a theoretical approach, in this paper, our approach is to consider a commonly used off-the-shelf radio - CC2420 attempt to design MAC protocols that can provide 1ppm or less error probabilities within deadlines ranging in 5-50ms.

In a joint computer and geo-science thesis we have built and deployed a wireless sensor network for measuring permafrost related parameters. Using these high-precision data, geo-scientists will be able to calibrate their heat flux models in order to better predict the stability of steep rock slopes in the alps. In this thesis it describes the computer science and system point of view and report on some lessons learned, especially in the domain of sensor design, power-awareness and reliable dataflow. The PermaSense thesis has two goals.

The first objective is to build and customize a set of wireless measurement units for use in remote areas with very harsh environmental monitoring conditions. Ultimately, the wireless sensor network (WSN) should be fully self-organizing, should operate unattended for years, and the technology should be easily reusable in other environmental monitoring contexts. The second goal consists in the gathering of environmental data that helps to understand the processes that connect climate change and rock fall in permafrost areas. Warming and thawing permafrost in steep alpine bedrock can slope stability and imperil the operation of man-made infrastructure (e.g. train tracks, roads and tourist resorts).

During 7 to 8 months out of a full year, the WSN infrastructure is unreachable due to extreme weather conditions: Air temperature can be as low as -30◦ C with strong winds, making it impossible to climb to the measurement points. Although the system must operate unattended most of the time, geo-scientists want to manage and configure it from their desk as well as having an advantage of context sensitivity allowing taking temperature measurements more effectively. The WSN contains therefore a GSM/GPRS node which connects the WSN to the Internet. Because a free line of sight to the GPRS equipped node cannot be guaranteed for all WSN nodes, and also due to the large distances between them (250-300m), a multi-hop routing scheme must be used. Although WSN platforms are now easily available on the market since many years, considerable soft- and hardware changes had to be made in order to cope with the above mentioned requirements. Similarly, the required high quality of the measured data led to many customs made solutions because the WSN community has not yet addressed environmental monitoring requirements with sufficient depth.

SPANNING TREE BASED ALGORITHM

In the paper [4] stated that (WSNs) employ battery-powered sensor nodes. Communication in such networks is very taxing on its scarce energy resources. Convergecast – process of routing data from many sources to a sink – is commonly performed operation in WSNs. Data aggregation is a frequently used energy-conversing technique in WSNs. The rationale is to reduce volume of communicated data by using in-network processing capability at sensor nodes. In that paper, they addressed the problem of performing the operation of data aggregation enhanced convergecast (DAC) in an energy and latency efficient manner. They assumed that all the nodes in the network have a data item and there is an a priori known application dependent data compression factor (or compression factor), c, that approximates the useful fraction of the total data collected. The paper first presents two DAC tree construction algorithms. One is a variant of the Minimum Spanning Tree (MST) algorithm and the other is a variant of the Single Source Shortest Path Spanning Tree (SPT) algorithm. These two algorithms serve as a motivation for our combined algorithm (COM) which generalized the SPT and MST based algorithm. The COM algorithm tries to construct an energy optimal DAC tree for any fixed value of α (= 1 - У), the data growth factor.

One important function of many wireless sensor networks (WSNs) is to gather data from hostile or remote environments. It is expected of such networks to work untended for a long duration. Due to limited energy resources, the above requirements put constraints on the energy usage. Examining various functionalities of sensor networks, communication can be singled out as one function that devours big share of the energy resources. Data aggregation is an energy conservation technique which tries to reduce the volume of data communicated by collecting local data at intermediate nodes and forwarding only the result of an aggregation operation, such as min and max, towards the sink node. Since a convergecast operation usually follows a broadcast operation [11], the path taken by a broadcast packet is also used for aggregating data in the convergecast. However, research shows that performing data aggregation along this routing path is not energy efficient [10]. In [11], authors study the general data aggregation problem and propose several (suboptimal) data aggregation techniques. The general data aggregation problem is – given m sources and one sink in a n node network (m < n), find a minimum weight sub graph that includes all sources. This is a well known NP-complete problem, known as the Steiner Tree Problem (STP) [14].

There are many approximation algorithms for solving STP [15–18]. From sensor networks' perspective, in the literature there are several heuristic approaches to solve this problem [11, 12]. The problem addressed in this paper is an important special case of the general data aggregation problem in which all the nodes in the network are source nodes. We refer to the task of collecting data from all the nodes in the network while performing data aggregation at intermediate nodes as a DAC operation. The paper addressed the problem of optimal implementation of DAC operations incorporating constraints such as data compression at intermediate nodes. Data compression factor c 2 [0, 1] is used to denote the effectiveness of aggregation in reducing the data volume in comparison to the volume of the input data at an intermediate node

In order to ensure collision-free data aggregation, the nodes are scheduled using a combined Code-Division Multiple Access (CDMA) and Time-Division Multiple Access (TDMA) based channel allocation algorithm. Latency of the proposed algorithms is improved by introducing a concept called b-constraint. This rule places an upper limit on the number of children each node in the tree can have. This limit is soft in the sense that b-constraint is violated in cases where there is a risk of a node being left out of the tree. Network lifetime is also observed as a by-product while running these algorithms.

Time optimal energy efficient packet scheduling algorithm with periodic traffic provides raw data convergecast from all nodes to the sink. Algorithm achieves the bound when the interference is eliminated. In simple interference model each node has circular transmission range, at the same time cumulative interference from multiple sender are avoided. While considering the multiple frequencies, estimate the effects of transmission power control by using physical interference and overlapping channels. This is done by using impact of the routing topologies. Later the work focused on TDMA based MAC protocol for high data rate in WSN. Tree MAC consider a difference load at different levels of routing tree. The time slots are assigned according to the depth of the root node, that is hop count, the nodes closer to the sink are assigning more number of slots than the number of children in order to diminish the congestion. Tree MAC operates on single channel achieves 1=3 of the maximum throughput. Sink remains the bottleneck, sending data by selecting different shortest path does not reducing the schedule length. In this paper the improvement is due to the routing structure using the minimal spanning trees for data gathering, where the number of nodes in a sub tree is not more than half the total number of nodes in the remaining sub trees.

The performance of data collection in sensor networks can be characterized by the rate at which sensing data can be collected and transmitted to sink nodes. The delay of data collection is the time to transmit one single snapshot to sinks from sensors. Considering the size of data in the snapshot, we can define delay rate as the ratio between the data size and the delay. When multiple snapshots from sensors are generated continuously, data transport can be pipelined in the sense that further snapshot may begin to transport before root node receive the prior snapshot. The maximum data rate at the root node to continuously receive snapshot data from sensors is the capacity of data collection. The capacity is always larger than or equal to the delay rate. Both delay rate and capacity reflect that how fast the root node can collect sensing data from all sensors.

The main objective of the scheme is energy-efficient continuous data collection by taking into consideration the temporal correlation in sensor data. Temporal correlation in sensor data is considered as an advantage and the next instance value can be predicted using previous instance values with the help of suitable prediction algorithms. The prediction algorithms will run simultaneously on both source node and the root node. If the predicted value exceeds certain threshold value in source then the difference between sensed value and the predicted value will be transmitted to the sink, else the predicted value at the root node will be used as the data for that instance.

REFERENCE LINKS

[1] D. Marco, E. J. Duarte-Melo, M. Liu, and D. L. Neuhoff. On the Many-to-One Transport Capacity of a Dense Wireless Sensor Network and the Compressibility of its Data. In Proc. of the 2nd International Workshop on Information Processing in Sensor Networks (IPSN), 2003.

[2] K. K. Chintalapudi and L. Venkatraman, “On the design of mac protocols for low-latency hard real-time discrete control applications over 802.15.4 hardware,” in IPSN ’08, pp. 356–367.

[3] I. Talzi, A. Hasler, S. Gruber, and C. Tschudin, “Permasense: investigating permafrost with a wsn in the swiss alps,” in EmNets ’07, Cork, Ireland, pp. 8–12.

[4] S. Upadhyayula and S. Gupta, “Spanning tree based algorithms for low latency and energy efficient data aggregation enhanced convergecast (dac) in wireless sensor networks,” Ad Hoc Networks, vol. 5, no. 5, pp. 626–648, 2007.

[5] T. Moscibroda, “The worst-case capacity of wireless sensor networks,” in IPSN ’07, Cambridge, MA, USA, pp. 1–10.

[6] Imrich Chlamtac, Shay Kutten, Tree-based broadcasting in multi-hop radio networks, IEEE Transactions on Computers C-36 (10) (1987).

[7] Imrich Chlamtac, Orly Weinstein, The wave expansion approach to broadcasting in multi-hop radio networks, IEEE Transactions on Communications 39 (3) (1991).

[8] Wendi Rabiner Heinzelman, Anantha Chandrakasan, Hari Balakrishnan, Energy-efficient communication protocol for wireless micro sensor networks, in: Proceedings of the Hawaii International Conference on System Science, January 2000.

[9] Rex Min, Anantha Chandrakasan, Energy-efficient communication for ad-hoc wireless sensor networks, in: Conference Record of the Thirty-Fifth Asilomar Conference on Signals, Systems and Computers, 2001, vol. 1, 4–7 November 2001.

[10] Sarma Upadhyayula, Valliappan Annamalai, Sandeep Gupta, A low-latency and energy-efficient algorithm for convergecast in wireless sensor networks, in: IEEE Global Communications Conference, 2003.

[11] Bhaskar Krishnamachari, Deborah Estrin, Stephen Wicker, Impact of data aggregation in wireless sensor networks, in: International Workshop on Distributed Event-Based Systems (DEBS’02) Vienna, Austria, July 2002.

[12] Chalermek Intanagonwiwat, Deborah Estrin, Ramesh Govindan, John Heidemann, Impact of network density on data aggregation in wireless sensor networks, in: Proceedings of International Conference on Distributed Computing Systems (ICDCS), Vienna, Austria, July 2002.

[13] Ian F. Akyildiz, Weilian Su, Yogesh Sankarasubramaniam, Erdal Cayirci, Wireless sensor networks: a survey, Computer Networks 3 (2002) 393–422.

[14] Steven S. Skeina, The Algorithm Design Manual, Springer-Verlag, New York, 1997, pp. 339–342.

[15] Marek Karpinski, Alexander Zelikovsky, New Approximation Algorithms for the Steiner Tree Problems, Journal of Combinatorial Optimization 1 (1997) 47–65.

[16] H. Takahashi, A. Matsuyama, An approximate solutions for the Steiner problem in graphs, Mathematica Japonica 6 (1980) 573–577.

[17] Hans J. Promel, Angelika Steger, RNC-approximation algorithms for the Steiner tree problems, in: Proceedings of 14th Annual Symposium on Theoretical Aspects of Computer Science, 1997, pp. 559–570.

[18] Alexander Zelikovsky, An 11/6-approximation algorithm for the network Steiner problem, Algorithmica 9 (1993) 463–470.