Wireless Sensor Networks

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INTRODUCTION

The origins of networks of sensors can be traced back to the 1980s when DARPA initiated the distributed sensor networks program. However, recent advances in microprocessor fabrication have led to a dramatic reduction in both the physical size and power consumption of such devices. Battery and sensing technology, as well as communications hardware, have also followed a similar miniaturization trend. The aggregation of these advances has led to the development of networked, millimeter-scale sensing devices capable of complex processing tasks. Collectively these form a wireless sensor network (WSN), thus heralding a new era of ubiquitous sensing technology and applications. Large-scale deployments of these networks have been used in many diverse fields such as wildlife habitat monitoring (Mainwaring, Polastre, Szewczyk, Culler, & Anderson, 2003), traffic monitoring (Coleri, Cheung, & Varaiya,, 2004), and lighting control (Sandhu, Agogino, & Agogino, 2004).

A number of commercial WSN platforms have been launched in recent years. Examples include the Mica family (Hill, 2003), Smart-Mesh (http://www.dust-inc.com), Ember (http://www.ember.com), iBeans (Rhee, Seetharam, Liu, & Wang, 2003), Soapbox from VTT (http://www.vtt.fi/ele/research/tel/projects/soapbox.html), Smart-Its (http://www.smart-its.org), and the Cube sensor platform (O'Flynn et al., 2005). As the miniaturization of the constituent components of a WSN continues unabated, power consumption likewise diminishes, thus the current generation of sensors can function perfectly for years using standard AA batteries (Polastre, Hill, & Culler, 2004). Alternative solutions may not require any batteries; for example iBeans (Rhee et al., 2003) coupled with an energy harvester can operate by scavenging energy from tiny vibrations that occur naturally. Miniaturized solar panels are another possible solution for outdoor operation. Production costs of single nodes are estimated to be less than a dollar, a significant cost reduction over the price of older sensor models, thus paving the way for large-scale WSN deployments, possibly consisting of a number of nodes several orders of magnitude greater than that in ad-hoc networks (Akyildiz, Su, Sankarasubramaniam, & Cayirci, 2002).

BACKGROUND

The main components of a WSN are gateways and sensor nodes. The sensor nodes can relay their sensed data either directly to the gateway or through each other depending on the scale of the network. In turn the gateway can send commands down to the nodes to, for example, increase their sampling frequency. In some networks, when the gateway is tethered to an adequate power supply, a greater transmission range can be achieved. This gives rise to an asymmetry in the data acquisition and control protocols, where control commands are sent directly to the node but the data sent from the node to the gateway is multi-hopped. Of course multi hopping of the control commands from the gateway can be used also.

Multi-hopping, while useful in extending the reach or scale of a WSN and reducing the overall transmission cost with respect to direct communication, does have its limitations. The cost of transmitting a packet can be greatly increased depending on the distance a node is from its gateway. Secondly, since nodes nearest the base station, that is, one hop away, will not only have to send their data but also that of all other nodes greater than a single hop, there will be a greater demand placed on the power supply of these nodes. This means that, in general, a node lifespan is inversely proportional to the number of hops it is away from the base station. To alleviate this problem, multiple gateways can be used, with the nodes only transmitting data to their local station. A second solution creates a hierarchy of nodes with varying power and transmission capabilities. Higher power nodes can act as gateways to the gateways for the lower powered sensors.

DEPLOYMENT CONSIDERATIONS

There are a number of issues to consider when deploying a WSN. The first and perhaps most significant is the number of nodes required in the deployment. The quantity of nodes required will primarily be governed by the size of the area to be monitored and the frequency of the sampling required. In general, the more nodes there are in a given WSN, the better the quality of data; however there is a corresponding increase in the time required for processing. Given that the choice on node density has been made, another factor still remains—the node sampling frequency. The choice of this value will depend on what aspect of the environment is being monitored and the power resources available on each node. If the sampling frequency is too high, more power will be consumed than is necessary. However, if it is too low, important events could be missed. A useful strategy might be to alter this value opportunistically so as to deliver optimum performance.

Getting the sensed data from the node requires the wireless transmission of a data packet, a process that can consume a significant portion of the available power resources. One transmission can occur per sensed value when a real-time picture of the environment is required. Or multiple readings can be bundled into a single message. Alternatively the node may intelligently decide not to transmit a packet if, for example, no change in the sensed value had occurred. This can dramatically increase the longevity of the node, and if this is a universal policy adopted by all nodes in the WSN, the lifespan of the WSN can be extended.

Due to the battery operation of the nodes, power management is critically important to the health of a WSN. Another approach to performing power conservation is to enable redundant sensors to hibernate. The rationale behind this is that a sensor consumes little or no power while asleep, and so the more nodes that are hibernating, the less power is being consumed collectively by the network. A hibernating node cannot forward any sensed data, effectively reducing the spatial sampling frequency. Therefore, caution must be exercised when selecting which nodes to hibernate.

Two broad approaches exist for selecting nodes for hibernation. The first is based on defining a sensing radius for each individual sensor. An area is covered if all points with the sensed area lie within the sensing range of at least one sensor. When there are points covered by more than one sensor, it may be possible to hibernate redundant sensors without breaking the coverage constraint.

An alternative approach uses the data being received by nodes. It is based on interpolation and assumes that the required node density exists. Given a collection of nodes, it is possible for them to interpolate the sensed medium at a required point, assuming an interpolation function exists. By interpolating at the point of an individual node, an interpolated value can be obtained. By comparing this to the actual sensed value, an interpolation error can be derived. If this error is less than a particular threshold, then this node is deemed redundant and will hibernate for a predefined period of time before rechecking its redundancy.

Another fundamental issue for practical WSNs is that of sensor calibration (Whitehouse & Culler, 2003). When two nodes observe different values in their sensed data, is it because they are seeing different events or because one or both of the sensors has malfunctioned? Of course calibration can be done prior to deployment, but if the malfunction causes its accuracy to degrade over time, then a recalibration must occur on the fly after deployment. This is a significant problem, since the environment in which the nodes are sensing usually cannot be controlled for the calibration to occur. When sampling the environment, it may be a requirement for all the sensors to sample at the same point in time. This requires a clock synchronization technique that will work over the entire network, and this is quite a difficult task to perform on such computationally challenged devices.

Multi-hop routing can introduce a considerable lag between the time a message is sent from the node and the time it is received at its destination. When the destination is a gateway, it will in turn send control commands to the network based on the data it receives. These control commands may also be multi-hopped to their destination. The aggregate delay can be unacceptable and is usually symptomatic of an overburdened gateway. The introduction of an additional gateway that efficiently partitions the network would alleviate this issue.

A final issue with a practical deployment of a WSN is that of programming and debugging the nodes themselves. A node considered to have one of the richest user interfaces consists of three LEDS, allowing eight program execution states to be displayed at any given point in time. To alleviate this, a methodology has been developed to allow the development of applications off the nodes so that accuracy of the approach can be verified (Tynan, Ruzzelli, & O'Hare, 2005).

APPLICATION CONSIDERATIONS

The autonomous nature of the wireless sensor networks makes the technology versatile with respect to applications. Sensors can be effectively deployed for monitoring and detecting of malfunctioning industrial machinery during normal production activity. Moreover, as no infrastructure is needed, their deployment is immediate and highly adaptive to the environment in which they operate. By means of

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