ISSN 2278-3091

International Journal of Advanced Trends in Computer Science and Engineering, Vol. 3 , No.2, Pages : 08 - 11 (2014)
Special Issue of ICACE 2014 - Held on March 10, 2014 in Hotel Sandesh The Prince, Mysore, India

A Review of Cross-Layered Approach in Wireless Sensor Networks

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Abstract: Sensor networks offer many attractive low cost solutions to monitor environmental conditions. In almost all of its applications there is no existing infrastructure for communication. Therefore, it is crucial for sensor nodes to survive on small sources of energy and communicate using a wireless channel. For this the communication need to happen in an efficient manner. This can be achieved with help of cross-layered approach of implementing a protocol. The goal of this paper is to review some of the existing cross-layering methods which will be helpful for future research in the area.

Key words: Cross layering, Review, Wireless sensor networks.

INTRODUCTION

As research in the field of low-power embedded systems was done, new possibilities were thought for sensing applications which led to the implementation of wireless sensor networks. A wireless sensor network is basically a wireless network consisting of tiny computing devices. These devices are autonomous and are distributed over a particular area. Each of the tiny computing devices (called a sensor node) is equipped with a sensor, a wireless radio, a processor, and a power source. Earlier, sensor networks consisted of small number of sensor nodes that were wired to a central processing station, but nowadays, the focus is more on wireless distributed sensing nodes. The wireless sensor network is composed of a large number of these sensor nodes, which are very densely deployed.

A wireless sensor network can be deployed in a physical environment in order to monitor a wide range of environmental phenomena. But in almost all the cases, the environment to be monitored does not have an existing infrastructure for energy and/or communication. Therefore, it is crucial for sensor nodes to survive on small sources of energy. Since these sensor nodes have limited memory and may be difficult-to-access (due to deployment), a radio is used for wireless communication to transfer the data to a base station via sink node. A battery is the main power source in a sensor node. However, secondary power supply such as solar panels may be added to the node depending on the requirement and the location of deployment. The sensor nodes have to perform the tasks of monitoring and collecting data, assessing and evaluating the information, storing the information and sending the useful data to the external network respectively. Each sensor node works in collaboration with the other nodes in order to convey the message to the sink node. So, if a few nodes fail then topology of the network around that area has to be changed and whole of the message has to be retransmitted thus reducing the efficiency of the network and wasting battery power. To counter this, recent research has shown that if cross-layered integrations and design techniques are implemented, the performance of the network at low energy is improved significantly.

The protocol stack of a wireless sensor network consists of five layers: application layer, transport layer, network layer, data link layer and physical layer [1]. The protocol stack is in 3D as Power Management Plane, Mobility Management Plane and Task Management Plane can work simultaneously on all the five layers of the stack. The power, mobility, and task management planes monitor the power, movement, and task distribution among the sensor nodes respectively

APPLICATIONS

Some of the major application areas of wireless sensor networks are as follows:

- Military
  - Monitoring the equipment and ammunition of friendly forces.
  - Battlefield surveillance.
  - Reconnaissance and targeting of opposing forces and terrain.
  - Assessment of battle damage.
- Disaster Management
  - Forest fire detection.
  - Flood detection.
- Health
  - Monitoring doctors and patients inside a hospital.
  - Drug administration.
- Home
  - Home automation.
  - Smart environment.
- Traffic Control
  - Vehicle tracking and detection

CROSS-LAYERED APPROACH

A cross-layered design is that in which a protocol is designed by exploiting the dependence between of the protocol to obtain performance gains. This is done because traditional layered architecture is not suitable for wireless networks in most of the cases.

Let us take into consideration three layers say A,B,C where A is the highest layer and C is the lowest layer. Now, there is no direct interface between A and C but need may arise for A and C to communicate at runtime. The traditional layered approach may not be suitable for this kind of situation. Therefore, using cross layered approach A and B can be joined to make a single super layer and a protocol can be designed for this layer independently. Now data can be shared amongst A and B and when needed can be transferred to C.

As data can be shared between different layers, thus reducing overhead, if a cross layered approach is used, therefore this makes them more efficient than simple layered approach. Therefore, research in the field of cross layered approach in wireless sensor networks can be helpful in making them more efficient.

CROSS-LAYER INTERACTIONS

According to the cross-layer design approach, two or more layers can be joined and their parameters can be retrieved and/or changed with the objective of making the system optimised. Different cross layered interactions can be employed according to the problem at hand. The design of the cross layer should be such, that each of the layer is designed by considering the interdependencies between the other layers. Some of the cross layered interactions are explained below. The overview of different interactions is shown in Table 1.

Routing, MAC, and Link optimization approach

As its name suggest, this approach implements a cross layer design between the link layer (data link), MAC layer and the routing layer (network layer) [2]. In this design, the nodes become active in their assigned time slot. Transmission of data takes place when the node reaches active mode at the assigned time slot. After the data is transmitted the node again goes to sleep mode to save battery power. The node enters the third mode i.e. the transient mode when that particular node reaches the particular time slot when it has to wake up from sleep mode to transmit data (i.e. go into active mode). This approach not only makes the system energy efficient but also can be used to maximize a node's life. This is achieved by link adaption. To calculate the energy consumed by the node, both routing and scheduling are optimised along with link adaption. It is due to the fact that link adaptation can help in significant reduction of transmission time between the nodes, it can be said that this approach can make the system efficient as it reduces the energy consumption across the nodes.

Transport, Network and MAC cross-layer approach

This approach is similar to the routing, MAC and link optimization approach combines transport, network and MAC layer into a single module [3]. In this the functionalities of these layers are also combined. In this approach, a node has the choice of participating in a transmission. The choice is made by the node on the basis of a set of four conditions i.e. the node will participate in the communication if and only if all the four conditions are satisfied. The conditions are as follows: i) The link should be reliable for communication i.e. the signal to noise ratio must be above the minimum specified threshold. ii) There should be no congestion at the node. iii) The data must be transmitted efficiently i.e. no bottleneck should be there. This condition also prevents buffer overflow as the amount of input will be controlled so that the buffer cannot be overflowed. iv) The node must have at least the minimum energy required for participation in communication. As all the four conditions have to be met before the communication to start, a reliable event driven communication is achieved along with energy efficiency. As the conditions have to be first met therefore, the nodes act in a systematic manner to forward the packets using the receiver based routing. The routing level (network layer) in each node is used to prioritize the nodes which will send the packet first. As everything happens in a structured way, this approach can achieve higher level of network performance and efficiency than simple layered protocol (whose layers are not crossed).

Optimal congestion-control and power-control

As its name suggest, this approach joins congestion control with power control i.e. Transport and Physical layers are joined with a goal to increase energy efficiency [4]. In this the communication process is divided into time slots and at each of the time slots four simultaneous operations are performed viz.: update delay due to weighted queue at each intermediate node, measurement of total delay at source node for updating TCP window size, calculation and passing of received messages from transmitting node to other nodes, and finally analysis of the queuing delay and messages received in order to adjust the power for transmission at the source node. These four operations are performed simultaneously and form the basis of the optimal congestion control and power control approach.

Physical, MAC, and Routing layer optimization approach

This approach follows the optimization of the physical, MAC and network layer (routing) to form a cross layer [5]. The main purpose of this approach is to increase the life of the network by optimizing transmission, data rate and link schedule. This approach has four constraints viz.: flow conservation (balanced flow at each time slot in the network), energy conservation (energy consumed should be less than initial energy), range constraint (transmission power should be less than or equal to maximum transmission power and rate constraint (maximum data rate is defined for each node). if these four constraints are taken into consideration while designing the cross layer then lifetime of the network can be increased as we can get optimal transmission power at each node.

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Table 1: Overview of different cross layer interactions

Cross Layer Interaction	Aim
Routing, MAC, and Link optimization approach	To minimise the network's overall energy consumption
Transport, Network and MAC cross-layer approach	To achieve efficient and reliable event based communication with minimum energy expenditure
Optimal congestion-control and power-control	To increase the end-to-end throughput and energy efficiency.
Physical, MAC, and Routing layer optimization approach	To increase network lifetime and improve bandwidth efficiency

CROSS-LAYER TECHNIQUES

XLP: A Cross layer protocol for efficient communication in wireless sensor networks

XLP is based on the initiative determination concept using which the nodes can make distributed decisions for communication based on certain factors [6]. XLP involves the cross layer interaction between MAC, Network and Transport layer. This allows the nodes to incorporate required functionalities into a single protocol by taking into consideration the channel effects. The XLP improves the throughput and energy efficiency of the system as compared to traditional layered approaches.

In this approach, the potential receivers first contend for packets and then become the next hop. The nodes which are already highly congested cannot take part in the communication. This is made sure using the cross layer congestion control implemented in this approach. Angle based routing is used to avoid local minimum. The receivers then adapt to communication parameters based on current channel conditions. In this approach, the nodes also employ a distributed duty cycle operation to minimize energy consumption and protocol overhead.

Prolonging the lifetime of a wireless sensor network by cross-layer interaction

This approach uses MAC and Network (routing) layer for its cross layer design [7]. In this approach, a self organizing medium access control protocol is used which uses an algorithm to decide the grade of participation of sensor node in creating a network on the basis of local information and an efficient routing protocol. In this approach, each active node periodically listens to the channel and broadcasts a short control message. The information is piggybacked in these control messages at low energy costs and the same is used for creating a maximal set of independent nodes which in turn creates the connected network. The nodes in this connected set are active while the nodes outside this network are passive and hence save energy. The information in the control message is also used to establish and maintain efficient routes by the routing protocol. The routes are established on the basis of local topology information; therefore, routes are re-established even when they are disconnected.

Adaptive low power listening for wireless sensor networks

In this approach, cross layering between routing (network) and MAC layer is done [8]. In this approach, greedy local decisions are used for optimizing the global power consumption as well as load balancing in the sensor network. Each node can change the behavior of its routing and MAC layer with the help of its local and neighborhood state information. In this approach, a node can set the routing cost of its neighbors according to the state and can also change their behavior according to the cross layer state representation. This means that each node can change its radio duty cycle in accordance with its current local and neighborhood states. Thus this approach is helpful in minimizing the idle listening power consumption.

Energy efficient cross-layer design protocol by using token passing mechanism for WSN

This approach also uses MAC and Network (routing) layer in its cross-layer design [9]. The fundamental principle of this approach is that whenever a node receives a packet, it is forwarded only if it is forwarded by a higher node. This means that the data can flow only towards the base station and not away from it. This is made sure by a token passing procedure at the network (routing) layer.

Table 2 shows the overview of different cross layered techniques described above.

Table 2: Overview of different cross layered techniques

Technique	Cross-layer interaction	Fundamental Points
XLP: A Cross layer protocol for efficient communication in wireless sensor networks	MAC, Network and Transport layer	• Nodes contend • Decongested nodes only • Receivers can adapt
Prolonging the lifetime of a wireless sensor network by cross-layer interaction	MAC and Network layer	• Active nodes broadcasts control message • Information piggybacked on control message
Adaptive low power listening for wireless sensor networks	MAC and Network layer	• Greedy Local decisions used • Local and neighborhood information used to set node behavior
Energy efficient cross-layer design protocol by using token passing mechanism for WSN	MAC and Network layer	• Unidirectional flow of data • Token passing procedure at network layer

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CONCLUSION

A wireless sensor network has a vast array of applications many of which include deployment in locations which are not easily accessible which may lead to difficulty in maintenance of nodes. Therefore, the network must be efficient so that resources are not wasted as it may lead to failure of the network due to inability to access faulty nodes. So for improving the overall efficiency of the network, cross-layered approach is a very vital part in the design and implementation of a wireless sensor network. In this review, the fundamentals of cross-layered approach are explained along with different kind of interactions and techniques. The study of this review can be helpful for understanding the concept of cross-layering and carrying out further research in the area of wireless sensor networks.

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