A Review on Cross Layer Routing Techniques

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Abstract- Ever since wireless sensor networks (WSNs) have emerged, different optimization techniques have been proposed to overcome their constraints like energy efficiency, delay, finding the best route, etc. Furthermore, the proposal of new applications for WSNs has also created new challenges to be addressed. The concept of Cross-layer gave a verity of optimization techniques to the world of sensor networks and the approaches have proven to be the most efficient optimization techniques for these problems, since they are able to take the behavior of the protocols at each layer into consideration. Thus, this survey proposes to identify the key problems of WSNs and gather available crosslayer solutions for them that have been proposed so far, in order to provide insights on the identification of open issues and provide guidelines for future proposals. In this paper, the need for cross layer design in WSN and the interaction between the layers is discussed first and later we discussed the different types of cross layer techniques

Index Terms- Wireless Sensor Networks, Optimization Techniques, Cross Layer design, Constraints.

I. Introduction

Due to the dynamic topology, limited resources and unpredictable channel conditions, the strict layered design is not flexible enough to cope with the wireless sensor network environment. The widespread use wireless sensor networks be a more and more important and common way to provide Internet connectivity. The worldwide success of the Internet, mainly determined by a layered architecture, has promoted the adoption of a similar solution for wireless sensor network. However, a strict layered design is not flexible enough to cope with the dynamics environments, and will thus prevent performance optimizations. It is because of the unpredictability and unreliability of the underlying wireless medium that research on cross-layer design in wireless ad hoc network and sensor networks has recently attracted a significant interest [10].

The traditional approach to optimizing performance by separately optimizing different layers of the OSI model may not be optimal. In order to obtain the best results, it might be necessary to perform optimization using the information available across many layers. The concept of cross-design is based on architecture where the layers can exchanges information in order to improve the overall network performances. Therefore, various cross-layering approaches, where protocol layers actively interact, exchange inherent layer information and fine tune their parameters according to the network status are becoming increasingly popular.

In WSN (wireless sensor networks) the node has small volume and uses the battery for energy supply, therefore has created that node's processing, memory property, communication range and energy is limited. In WSN, reducing the end-to-end delay and the energy consumption is very important. The limitation of energy is a fundamental problem in wireless sensor networks (WSNs) because of the limited battery capacity of sensor nodes. Communication protocols for WSNs, including routing and MAC layer protocols should be designed energy-efficiently. Traditional wireless MAC protocols such as IEEE 802.11 are not available for this purpose; since in these protocols, nodes are required to keep awake to listen to the medium even when the network becomes idle. This inefficient idle-listening mechanism wastes substantial energy.

The literature survey is discussed in the rest of the paper.

A. Cross Layer Design

Generally speaking, cross-layer design refers to protocol design done by actively exploiting the dependence between protocol layers to obtain performance gains. This is unlike layering, where the protocols at the different layers are designed independently. Cross-layer design states that parameters of two or more layers can be retrieved and/or changed in order to achieve an optimization objective. The concept of cross-layering has been first proposed for TCP/IP networks, when wireless links were deployed. Since the TCP/IP stack has been proposed for wired connections, there was a loss of performance when wireless technology became part of existing networks.

Lately, cross-layering is a field that has been attracting more attention in WSNs research and it is still in its early development in this type of networks since it has not been deployed on many test beds or networks yet. Common goals of cross-layer optimizations in WSNs are reduction of energy consumption, efficient routing, QoS provisioning, and optimal scheduling, as can be verified throughout this work. There are several studies on cross layer protocols for WSNs. To address the receiver based contention, congestion control and duty cycling in WSNs. Some of the most used protocols on cross layer design and new protocol proposals are going to be presented, along with the optimizations they provide, in order to gather a small database on what has been proposed so far. Cross-layer design has been adopted on wireless sensor networks (WSNs) to improve their performance by discussing the state-of-the-art literature on the subject. Also, open issues on cross-layering will be identified to facilitate the work of researchers towards further improvements applied to WSNs.

After presenting the definition, we identify some basic types of cross-layer designs and present relevant examples from the literature. This serves four purposes: first, it clarifies and illustrates our definition of cross-layer design; second, it creates a taxonomy for classifying existing cross-layer design proposals; third, it highlights the different interpretations of cross layer design in the literature and shows how they can be seen in a more unified way; and finally, it provides a framework for evaluating the implementation concerns raised by different kinds of cross-layer design proposals. As expected, the different kinds of cross-layer design proposals raise different implementation concerns. After creating the taxonomy of the cross-layer design proposals, we similarly categorize and discuss the initial proposals for implementing cross-layer interactions and highlight briefly for which kind of cross-layer design proposals the different implementation methods are suitable. Differently from the conventional networks layers, WSNs consider only the following layers: application (APP), network (NWK or NET), medium access control (MAC), and physical (PHY). Although there is no transport layer, since it is complex and it would waste sensors energy, some WSN protocols have been designed for congestion control and reliable end-to-end communication.

B. Cross Layer Interaction

Cross layer interaction means allowing communication of layers with any other possibly non-adjacent layers in the protocol stack. Traditionally, the network protocols are divided into several independent layers. Each layer is designed separately and the interaction between layers is performed through a well-defined interface.

The main advantage of layering is architectural flexibility but layering approach is not efficient for wireless networks. Cross layering came into existence because of highly variable nature of links used in the wireless communication systems and due to resource poor nature of the wireless mobile devices there has been multiple research efforts to improve the performance of the protocol stack by allowing cross layer interaction by wireless systems. Because of QoS, energy consumption, poor performance, wireless links, mobility, packet loss, delay problems observed in the wireless networks much attention is paid in the cross layer interactions. Typically, sensor nodes avoid direct communication with distance destination since high transmission power is required to achieve reliable transmission. Instead in WSNs, sensor nodes communicate by forming a multi hop network to forward messages to the collector nodes, which is also called the sink node.

II. LITRATURE SURVEY

A. CLB (Cost Link Based) for routing

In paper [1], the physical layer (PHY) plays a very important role in wireless communication due to the challenging nature of communication medium. The power consumption of wireless devices heavily relies on physical layer. The medium access control (MAC) layer manages wireless resources for PHY layer and directly impact overall performance. This solved by defining a new cross layer scheme CLB (Cost Link Based) for routing [1]. Data aggregation with low energy consumption is task of finding extreme (maximum, minimum) sensor readings within a WSN. Extreme value aggregation has found many important applications in WSN development. Work by used compression to find approximate solutions to queries to deal with the large amount of data. Used a threshold and binary search technique similar to our approach to find order statistics, specifically concentrating on the median. The work did not explore extreme value aggregation with more than just a straightforward broadcast- converge cast search.

In short, at the beginning of the query, every sensor node in the tree passes the query to all of its children. Once all of the children return with the maximum readings of their own respective subtrees, the parent sensor node then returns only the maximum reading of its own subtree back up to its parent in the network. Building on top of this work, went further by avoiding a count of distinct data points in the network as well as use previous query results to improve performance. Both concentrate on an ad hoc tree structure for WSN. This problem can be overcome by the proposed cross-layer probabilistic data aggregation method offers superior performance while demanding much lower energy consumption than existing algorithms. In comparison to the naive method, which consumes power as O (N log (N)), our algorithm offers a marked improvement at O (1) [2].

B. Fairness in delay-aware cross layer data transmission scheme (FDRX)

In paper [3], particularly, delivery of time-critical data becomes a significant challenge. For instance, the impact of delay on smart grid applications, considering a WSN that is used for condition monitoring of wind turbines. Timely delivery of critical data has been found to be a significant challenge in such applications. This can be solved by designing separately fairness-aware cross layer scheme and a delay-aware cross layer technique for WSNs. But here it is proposed a cross layer scheme that is both fairness-aware and delay-aware. Our fairness in delay-aware cross layer data transmission scheme (FDRX) is based on delay-estimation and data prioritization steps that are performed before the data transmission by the application layer. [3].

C. Link Distance Reliability Cost (LRC) Based Cross Layer Route

Shortest path scheme is the most common criteria adopted by the conventional routing protocols proposed for WSNs. The problem is that nodes along shortest paths may be used frequently and the batteries may exhaust faster. The consequence is that the network may become disconnected leaving disparity in the energy and disconnect the networks. Therefore the shortest path is not the most suitable metric adopted for routing decision. We have considered the network that is less mobile. MAC and the physical layer information are explored for routing. It can be solved by designing the new routing protocol, concept of the minimum hop scheme is considered.

We propose Link distance Reliability Cost (LRC) based cross layer route discovery for WSN (Wireless Sensor Network) that improve the end-to-end throughput, delivery ratio and node energy consumption in WSNs. This approach also decreases the chance of loss of data because we have assured that battery capacity is not below the defined value [4].

D. TCLM Model

In paper [5] the authors build up a reputation space and trust space in WSNs, and define a transformation from reputation space to trust space. It is proposed a trust-based LEACH protocol to provide secure routing, which is an integration of a trust management module with a trust-based routing module. The trust management module is responsible for building trust relationships among sensor nodes with novel methodologies to provide efficient monitoring, trust exchange and evaluation.

The trust-based routing module is a modified version of original protocol with the same head-election algorithm and working phases, while having trust-based decision-making. A multi-angle trust mechanism for nodes in Wireless Sensor Networks which adding the sensing data and the node's energy in the factors of trust assessment in addition to communication , and new trust models to calculate the trust values of communication trust, the sensed data and the node's energy. The proposed a new protocol TTSN (Task-based Trust Framework in Sensor Networks) to construct a trust framework model in wireless sensor networks. The sensor node has different trust rating for different task.

The proposed model use watchdog scheme to observe the behavior in different events of these nodes and broadcast their trust ratings. The authors have proposed an approach called BTRM-WSN which is a bio-inspired trust and reputation model for WSNs aimed to achieve to most trustworthy path leading to the most reputable node in a WSN offering a certain service. It is based on the bio-inspired algorithm of ant colony system. Most of existing methods are designed for MANETs and suppose that each node have the full route from source to destination (i.e. designed for source routing), while for the hop by hop routing they discuss only one hop neighbors not along the full route, that is not suitable for WSNs. In addition to that, no one used the cross layer concept in computing and updating the trust values.

In paper [5] the data available at both DLL and Transport layer to make the network-layer decision more accurate, which improve the performance of the trust model. Wireless Sensor Networks (WSNs) are vulnerable to attacks (selfish or malicious i.e. misbehaving nodes) due to the nature of the wireless media, restricted resource and the natural co-operations of sensors. Therefore, the security issue is very critical in WSN. The decision making in a WSN is essential for carrying out certain tasks as it aids sensors establish collaborations. This can be solved by new model for trust in WSN, called A Trust-Based Cross-Layer Model, which use cross-layer concept (ACKs from data link layer and TCP layer) to design trust-based model for sensor networks that guarantee the trust route from source to sink and isolate the malicious node. [5].

E. Cross Layer Design for Routing

In [9], there is a growing interest in the use of WSNs in various applications, such as disaster management, border protection and security surveillance. In these applications, the sensor nodes are usually expected to be remotely deployed in large numbers and to operate autonomously in unattended environments. In WSNs, the transmission medium is shared by all nodes within each others' transmission range, and because of limited amount of energy and scarcity of the medium spectrum, choosing appropriate network architecture for routing is deemed to be an important step for sensor networks.

Transmission energy for transmitting a k –bit message to a receiver at distance d can be computed as

$$\mathbf{E_{Tx}(k, d) = E_{Tx-elec}(k) + E_{Tx-amp}(k, d) = E_{elec} * k \square \varepsilon * k * d^2}$$

There are two common network architectures in WSNs Multi-hop and hierarchical (i.e. clustering). To enable the system to cope with dynamic load and cover a large area of interest without service degradation, cluster-based routing protocols get more spotlight. We compare our SCL protocol with the performance obtained using LEACH-C.

F. Simulation Model of SCL

We propose to create a cluster-based MAC protocol that takes advantage of the mechanisms of both CSMA and TDMA protocols. The following assumptions are made in the architecture of the network:

1. All nodes are homogenous, i.e. all have equal capacity in terms of power, computation and communication capacity.
2. The nodes in the network are aware of information about themselves, like the node IDs, locations and energy levels.
3. Nodes are stationary.
4. The Sink node has unlimited resource.
5. The number of transmitting nodes is varying, which means the system is event-driven, and traffic load is dynamic.

The purpose of our work is to find a balance between contention- and schedule-based protocols in the real world simulation. As the typical cluster-based architecture, the sensor nodes in the network are divided into clusters with one cluster-head (CH) in each cell, and these cluster-heads form the backbone of the sensor network. Therefore, all nodes in one cluster only send data to their own cluster-head. As described in LEACH, to reduce the interference between clusters, we use CDMA for the communication between CHs and Sink, while the hybrid MAC protocol is used among nodes within each cluster.

Just as in LEACH, the operation of the protocol is broken into rounds. For each round, it begins with a set-up phase, when the clusters are formed. Then a steady state phase follows, when data is collected by the cluster-heads then transmitted to the sink. The time-line of such operation is depicted in Figure 1 below.

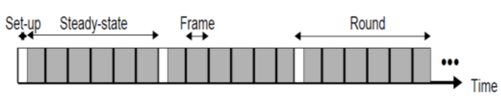

Figure 1: Shows an example of a Forwarding Mechanism

In figure 2 the following algorithm, describes the operation of the proposed protocol. A detailed explanation is given bellow, and shows the main protocol scheme of the network.

At the beginning of the procedure, all nodes, which are still alive, send the information about themselves, such as their locations and energy levels to the Sink node in one hop at a specific time, which equals to id*$T_{info\text{-}adv}$, where *id* is the identity number of the node, and $T_{Info\ -adv}$ is a parameter being set as

$$T_{Info\text{-}adv} = \frac{L_{hdr}+I_{interval}}{Bw} * g$$

Step 1: Information advertisements from all nodes to sink node.

Step 2**:** After Time out occurs, Cluster -Head election performed by the Sink.

Step 3: After Time out occurs, Clusters setup and Timeslots Assignment for each node in the networks.
(Step 1-3 is said to be SET-UP Phase)

Step 4: After Time out Occurs, Hybrid MAC Protocol implementation for Data Collection intra-duster.

Step 5: After Time out Occurs, Data Relay from Client Hosts to the Sink.

(Step 4-5 is said to be STEADY STATE)

Step 6: After Time out Occurs, goto step 1 and continue the procedure.

Figure 2: Shows the algorithm for Information Advertisement

A simple TDMA protocol is used based on our assumption that all nodes know this information. Furthermore, there is a timer for each state for avoiding overlapping [6].

G. MAC Layer Protocols

One of the main techniques for achieving low energy consumption in power restrained WSN is duty cycling. For this approach, the MAC protocol of each node periodically cycles between a sleep state and an awake state. To extend the network life span, each node must undergo a periodic sleep cycle for as long as it can, since the energy consumed in the sleep state is much lower than in the awake state.

Some MAC protocols such as S-MAC use fixed duty cycles. In some sensor network applications such as surveillance or object-tracking, nodes are inactive most of the time, but when an event happens, large amount of packets are generated which yields to network congestion. In such conditions, MAC protocols with fixed duty cycles experience data loss because they cannot adapt themselves to the heavy traffic load. Therefore, in order to solve this problem, new design approaches that adapt the duty cycles to the traffic load are being developed. Some load adaptable protocols are X-MAC, T-MAC and B-MAC. As the proposed algorithm considers the node's busyness level, it is necessary to have a MAC protocol which is adaptable to the traffic load.

1. T -MAC protocol is based on periodic sleep-listen schedules where nodes belonging to a cluster share the same schedule. This protocol has the advantage in that it reduces idle listening (since each node can only transmit during a fixed contention window) but it has the disadvantage that it needs synchronization.
2. B-MAC is an asynchronous protocol that sends long preambles to inform other nodes that they must wait for an incoming transmission. This method has the advantage that it does not need synchronization but it does force nodes into remaining awake during the whole preamble duration.
3. X-MAC is similar to B -MAC but with the advantage that it uses short preambles instead of long ones. This allows the nodes to send acknowledgments to the preambles to trigger the data transmission which reduces idle listening. For this reason and because it provides adaptation to the traffic load, we have selected X-MAC as the channel access method.

H. Congestion Control

The congestion control includes forwarding mechanism (Figure 3) and rate adjustment mechanism.

1. Forwarding mechanics: when a routing node receives a packet, it doesn't always forward the packet to a fixed node, but selects a downstream neighbor node in its routing table as the next hop randomly.
2. Adjustment mechanism: the specific algorithm of adjustment is as follows.

Step 1: When congestion occurs, the adjustment factors of probability n will update to n+1. Then the congestion degree C will reduce greatly. The probability of selecting it to be the downstream neighbor is also reduced. At the same time, the rate adjustment will change the rate R_c to $R_c/2$.

Step 2: When the congestion removes, the adjustment factors of probability n will reset to 0. The probability of selecting it to be the downstream neighbor will also increase. And the rate adjustment will change the rate R_c to R_c+R.

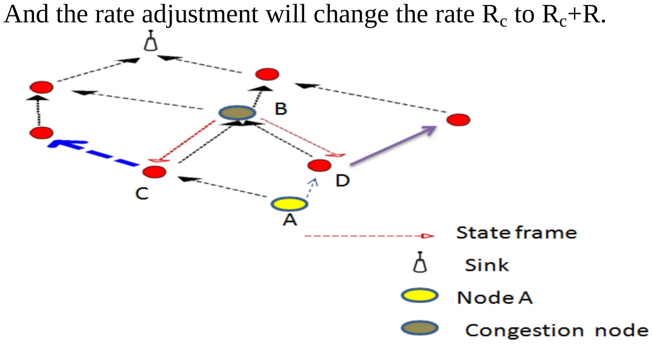

Figure 3: Shows an example of a Forwarding Mechanism

I. Cross-Layer Design Approaches

A growing number of recent papers are focusing on the cross-layer development of wireless sensor network protocols and frameworks. Recent works on WSNs demonstrate that cross-layer design approaches result in a significant performance improvement. This kind of design is focused on two main aspects are framework design and protocol design. The previous approaches can basically be classified depending on the layer interactions.

Therefore, there are protocol designs based on interactions between MAC and Physical layers, between MAC and Network layers, between Network and Physical layers, etc. This work focuses on the design of a multi-objective cross-layer algorithm for application to existing routing protocols based on the interactions between MAC, Network layer routing, Physical and Application layers. One example of cross-layer routing protocol design is the Energy Aware Routing Protocol proposed. This approach uses the residual energy of the nodes as a cost for the probabilistic selection of routes with the objective of equalizing the energy consumption of all nodes. This cross-layer method has the advantage that it considers the health of all nodes from the source to the destination and the disadvantage regards one parameter (the residual energy) as the performance metric, which does not provide much flexibility. Another example is the routing protocol that relies on local decisions in an attempt to equalize the energy consumption of all nodes. This approach uses the level of busyness of the nodes, the number of children of each node and the current node role to choose the paths locally. This methodology has the advantage that the routes can be maintained easily, adding very little overhead, and that many parameters can be included to make the routing decisions. Nevertheless, it has the disadvantage that decisions are made locally without considering the entire path from the origin to the destination.

These cross layer designs and other similar approaches are limited in that they attempt to only reduce or equalize energy consumption and this single performance optimization severely restricts their flexibility. The objective of the tunable multi-objective algorithm presented here is to balance multiple performance requirements, as demanded by the overlaying applications while also considering the limited available node resources so that the system response to application demands is dynamic and flexible. To achieve this goal, our cross-layer approach looks to exploit the advantages of previous cross layer methodologies, as highlighted earlier, firstly by considering the complete source-destination routing path for decision making, which gives a more global view of the network and secondly by using several parameters in selecting the path with an aim of providing flexibility. In addition, parameters can be weighted depending on the application running on the nodes and these weighting factors can be dynamically reset post network initialization if the application needs to change its priorities.

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