A Cross Layer approach for Performance Optimization in Wireless Sensor Networks using Cooperative Diversity

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Abstract
The performance of Wireless Mesh Networks is not optimal by using the conventional layered protocols (TCP-IP). Then the method of optimization at different layers of the protocol stack (TCP-IP) can help to achieve optimal network performance. This method usually results in a clean-slate protocol architecture that is different from the protocol architecture of WMNs. Such a difference actually demonstrates the need for a cross-layer design. Specific features pertaining to WMNs also show the need for cross-layer optimization across different protocol layers. In this paper, the need for cross layer design in WMNs is discussed first. Later in this paper we will discuss the different cross layer optimization schemes and we will compare the performance metrics such as throughput, end-to-end delay and PDR (packet delivery ratio) in multihop wireless sensor networks with and without user cooperative diversity.

Keywords
Cross Layer Optimization, Wireless Mesh Networks (WMNs), TCP-IP, Routing

I. Introduction
Wireless Sensor Networks are one of the most promising and a discussed technology in the last decade is the wireless technology which allows users to utilize devices that enable the access to information at any time any place. Wireless networks are comprised of devices that communicate through media such as radio signals and infra-red, and they are generally classified into two categories: infrastructure-based and Ad-Hoc wireless networks.

1. Infrastructure-based wireless network consists of base stations localized in convenient places, which provide wireless connectivity to devices within their coverage area. Examples of this category are Wireless Local Area Networks (WLANs) and cellular networks. A WLAN is a flexible data communication system implemented as an extension to a wired LAN within a building or campus.

2. Wireless Ad-Hoc networks do not have a pre-established infrastructure. Moreover, nodes connect to each other through automatic configuration when they are in transmission range and willing to forward data for other nodes. In this way, an ad hoc wireless network is formed which is both flexible and powerful.

A. Wireless Ad-Hoc Networks
Wireless ad-hoc networks can be further classified into the following different categories according to their applications

- Mobile ad-hoc Networks (MANETS)
- Wireless Sensor Networks (WSNs)
- Wireless Mesh Networks (WMNs)
- Hybrid Wireless Networks

1. Mobile Ad-Hoc Networks
The MANETs includes devices that are mobile nodes which provide the functionality required to connect users allowing them to exchange information in an environment with no pre-established infrastructure. Therefore, MANET is an infrastructure-less network with highly dynamic topology. Devices are free to move randomly and organize themselves arbitrarily; thus, the wireless network topology may change quickly and is unpredictable.

2. Wireless Sensor Networks
Wireless sensor networks are formed by spatially distributed tiny sensor nodes that cooperatively can gather and monitor physical parameters or environmental conditions and transmit to a central monitoring node. In addition, sensor nodes are equipped with a radio transceiver or other wireless communication device, a small microcontroller, and usually a battery as an energy source.

3. Wireless Mesh Networks
The Wireless Mesh Network (WMN) is a highly promising technology and it plays an important role in the next generation wireless mobile network. WMNs have emerged as important architectures for the future wireless communications.

Fig. 1 Wireless Networks Classification

Fig. 2: Wireless Mesh Networks
4. Hybrid Wireless Networks
The Hybrid wireless network is an Ad-hoc wireless network that contains a sparse wired network of base stations. The resulting network comprises regular nodes and wired connected base stations. In this way, we could have a traditional cellular network and an ad hoc network mixed together.

II. Background and Related Works

A. Cross Layer Optimization - Motivation
Why does the presence of wireless links in the network motivate designers to violate the layered architectures? There are three main reasons: the unique problems created by wireless links, the possibility of opportunistic communication on wireless links, and the new modalities of communication offered by the wireless medium [2]. On the other side, wireless links create several new problems for protocol design that cannot be handled well in the framework of the layered architectures. The classic case of a TCP sender mistaking a packet error on a wireless link to be an indicator of network congestion is an example [3]. Whereas on the contrary, wireless networks offer several avenues for opportunistic communication that cannot be exploited sufficiently in a strictly layered design. For instance, the time-varying link quality allows opportunistic usage of the channel [4], whereby the transmission parameters can be dynamically adjusted according to the variations in the channel quality, just to name one example. Additionally, the wireless medium offers some new modalities of communication that the layered architectures do not accommodate. For instance, the physical layer can be made capable of receiving multiple packets at the same time. The nodes can also make use of the broadcast nature of the channel and cooperate with one another in involved ways.

1. Different cross layer design approaches
Today there exists many cross-layer design proposals but the authors in [6] present a survey of several cross-layer design proposals from the literature based on the layers that are coupled. Here, we are more interested in how the layers are coupled, in other words, what kind of architecture violation has taken place in a particular cross-layer design. We note that the layered architecture can be violated in the following basic ways:

- Creation of new interfaces (Figs. 3A-C)
- Merging of adjacent layers (Fig. 3D)
- Design coupling without new interfaces (Fig. 3E)
- Vertical calibration across layers (Fig. 3F)

![Image](http://www.ijcst.com)

Fig. 3: The Different Types of Cross Layer Designs

We find that most cross-layer design proposals in the literature fit into one of these basic categories. We shall now discuss the aforementioned four categories in more detail and point out some relevant examples.

1. Upward Information Flow
A higher-layer protocol that requires some information from the lower layer(s) at runtime results in the creation of a new interface from the lower layer(s) to the higher layer, as shown in Fig. 3A. Suppose, if the end-to-end TCP path contains a wireless link, errors on the wireless link can trick the TCP sender into making erroneous inferences about the congestion in the network, and as a result the performance deteriorates. Creating interfaces from the lower layers to the transport layer to enable explicit notifications alleviates such situations. For example, the explicit congestion notification (ECN) from the router to the transport layer at the TCP sender can explicitly tell the TCP sender if there is congestion in the network to enable it to differentiate between errors on the wireless link and network congestion [3]. Examples of similar upward information flow are also seen in the literature at the MAC layer (data link layer in general) in form of channel-adaptive modulation or link adaptation schemes [4]. The idea is to adapt the parameters of the transmission (e.g., power, modulation, code rate) in response to the channel condition, which is made known to the MAC layer (link layer) by an interface from the physical.

2. Downward Information Flow
Some crosslayer design proposals rely on setting parameters on the lower layer of the stack at runtime using a direct interface from some higher layer, as illustrated in fig. 3B. For example, applications can inform the link layer about their delay requirements, and the link layer can then treat packets from delay-sensitive applications with priority [7].

A better way to look at the upward and downward information flow is to treat them as notifications and hints, respectively, as proposed in [8]. Upward information flow serves the purpose of notifying the higher layers about the underlying network conditions; downward information flow is meant to provide hints to the lower layers about how the application data should be processed.

3. Back and Forth Information Flow
Two layers, performing different tasks, can collaborate with each other at runtime. Often, this manifests in an iterative loop between the two layers, with information flowing back and forth between them as highlighted in Fig. 3C. Clearly, the architecture violation here is the two complimentary new interfaces. As an example, we refer to the Network-assisted Diversity Multiple Access (NDMA) proposal [9], wherein the Physical (PHY) and MAC layers collaborate in collision resolution in the uplink of a wireless LAN system. Basically, with improvements in the signal processing at the PHY, it becomes capable of recovering packets from collisions. Thus, upon detecting a collision the base station first estimates the number of users that have collided, and then requests a suitable number of retransmissions from the set of colliding users.

4. Merging of Adjacent Layers
Another way to do cross-layer design is to design two or more adjacent layers together such that the service provided by the new superlayer is the union of the services provided by the constituent layers, as shown in fig. 3D. This does not require any new interfaces
to be created in the protocol stack. In general, the superlayer can be interfaced with the rest of the stack using the interfaces that already exists in the original architecture. Although we have not come across any crosslayer design proposal that explicitly creates a superlayer, it is interesting to note that the collaborative design between the PHY and MAC layers (discussed earlier with the NDMA idea) tends to blur the boundary between these two adjacent layers.

5. Design Coupling Without New Interfaces
   Another category of cross-layer design involves the coupling of two or more layers at design time without creating any extra interfaces for information sharing at runtime. We illustrate this in Fig. 3E. While no new interfaces are created, the implementation cost here is that it may not be possible to replace one layer without making corresponding changes to another layer. For instance, [5] considers the design of a MAC layer for the uplink of a wireless LAN when the PHY is capable of providing multipacket reception capability. Multipacket reception capability implies that the PHY is capable of receiving more than one packet at the same time. Notice that this capability at the physical layer considerably changes the role of the MAC layer; thus, it needs to be reconstructed.

6. Vertical Calibration Across Layers
   The final category in which cross-layer design proposals in the literature fit is what we call vertical calibration across layers. As the name suggests, this refers to adjusting parameters that span across layers, as illustrated in Fig. 3F. The motivation is easy to understand. Basically, the performance seen at the level of the application is a function of the parameters at all the layers below it.

   For example, [11] presents an example of vertical calibration where the delay requirement indicates the persistence of link-layer automatic repeat request (ARQ), which in turn becomes an input for deciding the rate selection through a channel-adaptive modulation scheme. Vertical calibration can be done in a static manner, which means setting parameters across the layers at design time with the optimization of some metric in mind. Static vertical calibration does not create significant consideration for implementations since the parameters can be adjusted once at design time and left untouched thereafter. Dynamic vertical calibration, on the other hand, requires mechanisms to retrieve and update the values of the parameters being optimized from the different layers.

B. Cross Layer Optimization Algorithms
   In the following section, instead of going through all combinations of cross-layer design, we will focus on the ones that are most critical for WMNs. Considering the TCP/IP protocol architecture, the protocol layers that contain most specific features of WMNs include MAC, routing, and physical layer as shown in fig.4.

   In some cases, the transport layer needs to be optimized with physical layer in WMNs. Thus, in the remaining part of this section, we will investigate the detailed protocols in cross-layer design between MAC and physical, between MAC and routing, and between physical and transport layers. Optimization algorithms across multiple layers are also discussed.

1. MAC/Physical Cross-Layer Design
   Cross-layer design between MAC and physical layers is more common than that between any other two layers, because MAC and physical layer are so close to each other. These techniques include the following typical categories.
   • Multiple coding and modulation schemes. When a different coding and modulation scheme is used, the transmission rate on a link also changes.
   • Advanced antenna techniques. The examples include directional antennas and smart antennas.
   • MIMO. Based on multiple antennas for transmission and reception and advanced signal-processing techniques, the transmission rate of a wireless link can be significantly increased by MIMO.
   • Orthogonal frequency-division multiplexing (OFDM) technologies. OFDM can be used to build OFDM/TDD, OFDM/FDD, or OFDMA systems, as specified in IEEE 802.16. It can also be used as a building block for ultrawideband (UWB) systems.
   • UWB. Very high transmission rate is achieved using ultrawideband. UWB can be pulse-based like direct-sequence (DS) UWB as specified by UWB forum [12] or OFDM-based like multiband-OFDM (MB-OFDM) supported by WiMedia Alliance [13].

2. Routing/MAC Cross-Layer Design
   A routing protocol of a multihop wireless network determines a path for any packet from its source to destination. In its simplest form, a routing protocol can just consider connectivity between nodes, i.e., as long as connectivity can be maintained, a routing path is set up. However, to enhance performance, other routing metrics and mechanisms must be taken into account.

   Routing/MAC cross-layer can be done in a simple loosely coupled scheme as follows. A routing protocol collects information in the MAC layer, such as link-quality, interference level, or traffic-load information, to determine the best routing path. Such a method can only achieve a limited performance gain, since the MAC layer is considered but not optimized accordingly. In order to optimize the performance of routing and MAC protocols together, the working mechanisms of a MAC protocol must be explored and optimized as part of the tasks of routing/MAC cross-layer design.

   It is well known that a MAC protocol can be reservation or random-access based. For a random-access-based MAC, no mechanism is available to fine-tune the MAC layer performance by considering information from the upper layer. Instead, a node just tries its best to access the medium. Such a MAC has a great advantage of simplicity and has another advantage of being decoupled from upper protocol layers. However, the shortcoming is that the MAC itself has low performance, and routing protocol can even have worse performance since no chance of cross-layer optimization is available. Such a problem reflects one of the many issues of applying CSMA/CA MAC protocol to WMNs. There are two possible solutions to this problem. One is to modify the random-access protocol so that it becomes closer to a reservation protocol. For example, the 802.11e hybrid channel-access control includes
mechanism of scheduling and reservation, which works together with CSMA/CA to improve the performance of 802.11 MAC. The other solution is to have overlay protocols. For example, we can develop a TDMA protocol overlaying CSMA/CA [14].

3. Transport/Physical Cross-Layer Design
In a multihop wireless network, the capacity of a link is usually variable due to factors such as interference, time-varying channel quality, fading, and so on. Without a fixed capacity in these links, an end-to-end transmission mechanism, i.e., a transport-layer protocol, needs to be optimized by considering the varying link capacity. This motivates the need for cross-layer design between transport layer protocol and physical-layer techniques. Transport-layer protocol can be simple or complicated, depending on what services need to be provided at the transport layer. The two most well-known transport-layer protocols are TCP and UDP. For UDP, the mechanism is very straightforward; a source node just sends its desired traffic rate without considering what will happen in the intermediate nodes and links from itself to the destination node. TCP works significantly differently. A source node needs to adaptively adjust its transmission rate according to the congestion condition in the network. The congestion can be real congestion on a certain link or poor quality in a link. Cross-layer design between TCP and physical layer for a multihop wireless network has been researched for several years. One method is the congestion-control algorithm of TCP which is optimized by considering the information collected from the physical layer in this the physical-layer information is used to differentiate packet loss due to congestion from that due to link-quality-related loss. Such optimization can only achieve limited performance improvement, because the interaction between TCP and physical layer is not considered. However, when a link is congested, the physical layer can adjust its parameters, like for example the transmit power, to avoid congestion, which will also help TCP achieve better performance. Similarly, when a link experiences low quality, the physical-layer parameters, such as coding rate or transmit power, can be adjusted to enhance the link quality.

III. Simulation Configuration

In this section, we illustrate the network configuration of our simulation study. We consider two topologies a grid and a random 25-node Multihop Wireless Sensor Network in which all nodes are stationary and they are not required to have the same number of radio interfaces. All nodes are mesh routers and the center node acts as a central mesh router that could be connected to a wired network, as shown in fig. 5 and fig. 6, respectively. Our main objective is to evaluate and compare the total power consumption of multihop wireless sensor networks with and without cooperative diversity. Our wireless sensor network design has the following assumptions and features:

• Each of the 25 nodes are itself acting as a node as well as a relay node.
• The path or flow from any node to the other node can be made using a maximum of two hops only that is the case of user cooperation diversity.
• We consider two multihop scenarios on the same network topology. In the first scenario, we assign only one hop for each node to the next node, this is called non cooperation. In the second scenario, we allow a maximum of two hops for communication between any two nodes provided that a node acting as relay node takes data from source node and sends it to the destination node.
• In each scenario, channels are statically assigned.
• We assume that there is no transmission error if there is no collision.
• The maximum distance from any node to its next hops is 100 meters.
• The maximum number of aggregated packets per frame is 15.

In order to achieve our objectives we use the MATLAB simulator version R2010a which has the necessary base structure for simulating many kinds of computer networks including the multihop wireless sensor networks which is the framework for this research. For our valuation we use the following three metrics in our study:
1. Link Flow Design: It is a plot to show the various paths the algorithm has used to transmit data from source node to the destination node. It is measured in b/s/Hz.
2. Total Power Consumption: Total Power consumption is the energy required by the source nodes to transmit the packets to destination nodes. It is measured in mW(milli watts).

IV. Simulation Results
In this section, we present the results of the experiments, which will be organized in three parts. In the first part, we show the link flow graph for the grid topology as shown in fig. 7.
In these two parts, we illustrate two scenarios in order to compare and demonstrate the improvement in terms of total power consumption, where the first scenario shows the link flow graph for the random topology of the wireless sensor networks as shown in fig. 8.

Finally, we present the third part; here we demonstrate the total power consumption in both grid and random topologies of the wireless sensor networks as shown in fig. 9. Here it can be clearly seen that there is less power consumption in grid and random topology using cooperative diversity. Total Power Consumption without using cooperative diversity is 20 mW and with user cooperation diversity it is somewhere around 18mW, which is quite an improvement.

V. Conclusion

In this paper, we have studied the cross layer optimization performance of multihop wireless sensor networks using cooperative diversity. Better network performance can be obtained by using Cooperative Diversity and using aggregated frame packets in a MAC/PHY cross layer design. We used MATLAB vR2010a tool to simulate the network. The extensive simulation results prove that total power consumption improves as we use cross layer design with cooperative diversity.

References


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