Implementing Cross-Layer Technology to Enhance Wireless Multihop Network Efficiency

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Abstract— The success of communication network has largely been a result of adopting a layered architecture. With this architecture, its design and implementation is divided into simpler modules that are separately designed and implemented and then interconnected. However, the layered structures in the existing networks are designed in layers, where protocols operate independently at each layer of the network stack. This approach provides flexibility with a modular design and standardization, but it may result in severe performance degradation when these protocols do not cooperate well. This is usually the case of wireless multihop networks, where noise and interference at lower layers affect the routing and congestion control performed at upper layers. Wireless links are unreliable and wireless nodes usually rely on random access mechanism to access wireless channel. Thus, the performance of link layer is not guaranteed, which will result in performance problems for the whole network. So, we need cross-layer design in order to improve the performance and achieve the capacity of wireless multihop networks. In this paper, we are using XPRESS, a cross-layer backpressure architecture designed to reach the capacity of wireless multihop networks. Instead of a collection of poorly coordinated wireless routers, XPRESS turns a mesh network into a wireless switch where packet routing and scheduling decisions are made by a backpressure scheduler. XPRESS is composed of a central controller, which performs backpressure scheduling based on the measured wireless network state, and also of the wireless nodes, which periodically provide the network measurements and execute the computed schedule using a cross-layer protocol stack. Transmissions over the network are scheduled using a throughput-optimal backpressure algorithm.

Keywords: CrossLayer Approach, TDMAC Protocol, Back pressure Architecture.

INTRODUCTION

Existing networks are designed in layers, where protocols operate independently at each layer of the network stack. However, the main commonality of these protocols is that they follow the traditional layered protocol architecture. While these protocols may achieve very high performance in terms of the metrics related to each of these individual layers and this approach also provide flexibility with a modular design and standardization, but they are not jointly optimized to maximize the overall network performance while minimizing the energy expenditure and it may result in severe performance degradation when these protocols do not cooperate well. This is usually the case of wireless multihop networks, where noise and interference at lower layer affect the routing and congestion control performed at upper layers. By considering the performance issues of wireless multihop networks, join to optimization and design of networking layers, i.e., cross-layer design, stands as the most promising alternative to inefficient traditional layered protocol architectures. In this paper, we can analyze the performance improvement of the networks by using a cross- layer approach. By review literature proposing precautionary guidelines and principles for crosslayer design, and suggest some possible research directions. I also present some concerns and precautionary considerations regarding cross-layer design architectures. The different layers of the network interface with each other for information transfer. In the cross-layer architecture the physically and medium access layer share information so that these information becomes available to the higher layers. The power control information of the physical layer and channel allocation information of the medium access layer are shared with the upper network layers.

Cross-layer architectures offer a radical alternative by advocating cooperation among the multiple layers of the protocol stack. At the core of these architectures is the back pressure scheduling algorithm. In essence, backpressure assumes a globally synchronized time-slotted MAC protocol as well as a centralized controller that both computes and disseminates a schedule (i.e., a set of links allowed to transmit) for each time slot. Moreover, the schedule computation requires the global knowledge of both per-flow queue backlogs and network state (i.e., link quality and link interference pattern), which therefore must be measured at the wireless nodes and provided to the controller in a timely manner.

RELATED WORK

Wireless Networks

Wireless Networks are a class of wireless networks intended for monitoring physical and environmental phenomena. The main task of sensor nodes is to collect specific data from surrounding environment and then route it to the base station or sink. Generally, sensor nodes observe and sense the phenomenon with a sensing module, process the data with a computing module, and send the data to a required destination over a radio interface with a communication module.

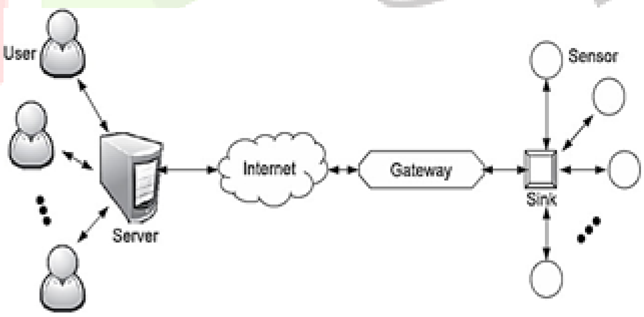

Fig.1:Wireless network architecture.

Wireless sensor network architecture is shown in Figure 3 & 4 in which sensor nodes are distributed over a particular area of interest to collect data, process them, and send them to a sink node for further processing.

Layered Approach

The Open Systems Interconnection (OSI) reference model divides the network architecture in to seven well defined logical layers, each layer responsible for some specific task. The real world implementation of the layered approach including TCP/IP (Transmission Control Protocol/Internet Protocol) protocol suite show the importance of layered architectures.

TDMA-Based MAC Protocols

In TDMA-based MAC protocol, the total time duration of communication is divided into a fixed number of timeslots. TDMA configures these time-slots into time-frames that repeat periodically. Each node in the sensor network is allocated a fixed number of time-slots and is allowed to transmit only in the allocated time-slots in each frame.

Interference Estimation

Passive approaches require monitors deployed throughout the wireless network to collect traffic traces, which are later analyzed offline. Active approaches use the available infrastructure to inject test packets into the network and measure interference.

Crosslayer approach

Cross layer design may be defined as, "the breaking of OSI hierarchical layers in communication networks" or "protocol design by the violation of reference layered communication architecture is cross-layer design with respect to the particular layered architecture". The breaking of OSI hierarchical layers includes merging of layers, creation of new interfaces, or providing additional interdependencies between any two layers.

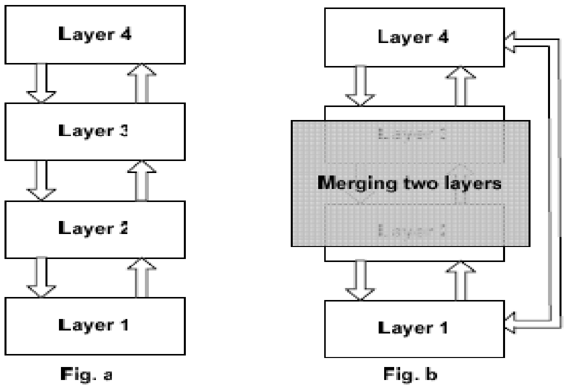

Fig.2: Example reference architecture with defined interfaces (Fig a.) and its violation (Fig. b)

Congestion Control

A wireless sensor network (WSN) may consist of tens or thousands of sensor nodes scattered in an area. When an event is detected, there is a sudden outburst of data. The data generated by the nodes increases and the offered load exceeds available capacity and the network becomes congested. Congestion is WSN can be transient (link level congestion) or persistent (node level congestion).

PROBLEM STATEMENT

Since wireless sensor networks (WSNs) have emerged, different optimizations have been proposed to overcome their constraints. Furthermore, the proposals of new applications for WSNs have also created new challenges to be addressed. Moreover, in wireless networks there does not exist a good interface between the physical and network layers. Wireless links are unreliable and wireless nodes usually rely on random access mechanism to access wireless channel. Thus, the performance of link layer is not guaranteed, which will result in performance problems for the whole network.

MOTIVATION

In order to improve the performance and achieve efficient optimality, we need to understand interactions across layers so we need cross-layer design, i.e., to exchange information between physical/link layer with higher layers in order to achieve better performance. Cross-layer 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 cross layer solutions for them that havebeen proposed so far, in order to provide insights on the identification of open issues and provide guidelines for future proposals.

PROPOSED SYSTEM

Xpress System Design

In this section we present the XPRESS system, cross-layer backpressure architecture for wireless multihop networks. To our knowledge, XPRESS is the first system to implement backpressure scheduling over a time-slotted MAC, as it was originally proposed in theory. We first provide a general overview of architecture, and then we detail the high-level system architecture, data plane designs.

Architecture

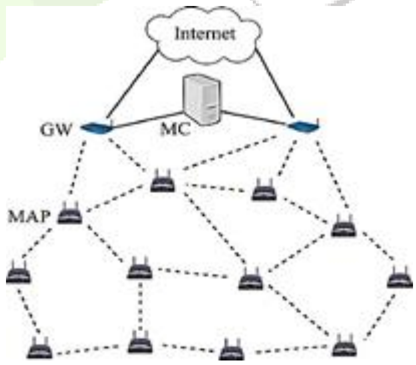

Fig.3:XPRESS architecture

XPRESS architecture composed of MAPs to provide wireless coverage to mobile clients, GWs to provide Internet connectivity, and an MC for wireless scheduling. In this XPRESS, the wireless network is composed of several mesh access points (MAPs), a few gateways (GWs), and a mesh controller (MC), as depicted in Fig. A. We use the term "node" to refer to a mesh node that can be either an MAP or a GW. The MAPs provide wireless connectivity to mobile clients and also operate as wireless routers, interconnecting with each other in a multihop fashion to forward user traffic. Mobile clients communicate with MAPs over a different channel, and thus are not required to run the XPRESS protocol stack. The

GWs are connected to both the wireless network and the wired infrastructure and provide a bridge between the two. The MC is responsible for the coordination of the wireless transmissions in the network, and it is analogous to a switching control module. In our design, the MC is deployed in a dedicated node in the wired infrastructure and connects to the gateways through high-speed links. In an alternative design, the MC could be implemented within one of the gateways, if necessary. At a high level, the operation of XPRESS can be described as follows.

XPRESS runs a slotted MAC protocol, where a sequence of slots is organized into frames. For each slot, XPRESS selects a set of noninterfering links to transmit based on the flow queue lengths and the network state. Each node thus maintains per-flow queues and monitors adjacent links to estimate interference and losses. The queue lengths and network monitoring results are periodically transmitted to the MCover an uplink control channel. Upon reception of this information, the MC updates its local topology.

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Backpressure Scheduling:

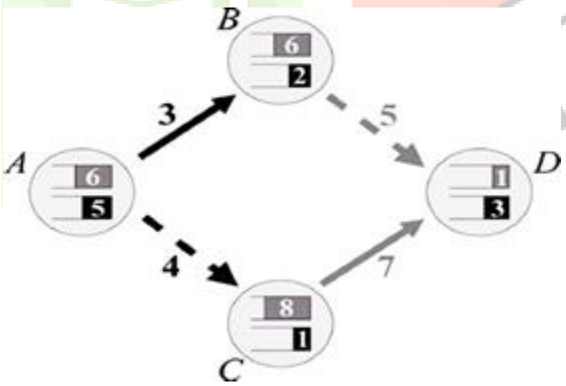

Fig. 4:Backpressure scheduling

Backpressure scheduling in a network with two flows, black and gray, from A to D. Links in sets {(A, B),(C,D)}(continuous)and{(A,C),(B,D)}(dashed)can be scheduled in the same slot.

The backpressure algorithm was introduced as a scheduling policy that maximizes the throughput of wireless multihop networks. Assuming slotted time, the basic idea of backpressure scheduling is to select the “best” set of non-interfering links for transmission at each slot. We now describe this idea in a 4-node network with two flows, black and gray, from node A to D, depicted in Fig. 4.2. Each node maintains a separate queue for each flow. For each queue, the number of backlogged packets is shown. Assume that we have two link sets,{(A,B),(C,D)}and {(A,C),(B,D)} shown as continuous and dashed lines, respectively. The links in each set do not interfere and can transmit in the same time slot. The scheduler executes the following three steps at each slot.

First, for each link, it finds the flow with the maximum differential queue backlog. For example, for link (A, B), the gray flow has a difference of 0 packets and the blackflowhasadifferenceof3packets.Themaximum value is then assigned as the weight of the link (see Fig.B). Second, the scheduler selects the set of noninterfering links with the maximum sum of weights for transmission. This requires computing the sum of link weights for each possible set. In the example, set {(A,B),(C,D)}sums to 3+7=10 and set {(A, C), (B, D)} sums to 4+5=9.

Third, the scheduler then selects the set with the maximum sum of weights, i.e., {(A, B), (C, D)} to transmit at this slot. Finally, packets from the selected flows are transmitted on the selected links, i.e., black flow on link (A, B) and gray flow on link (C, D). The same computation is then performed at every slot.

DataPlane:

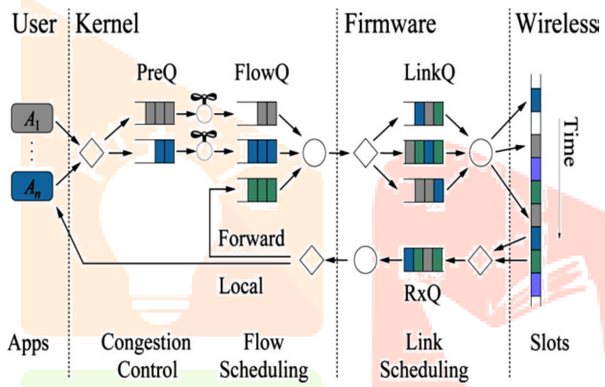

Fig.5:Data plane at XPRESS nodes.

Diamonds are packet classifiers, while circles are packet schedulers. The XPRESS data plane spans the transport, network, and MAC layers of the protocol stack, as depicted in Fig. 3. The transport and network layers implement congestion control and flow scheduling, respectively. The MAC layer implements link scheduling and a TDMA MAC protocol. The organization of these modules into host OS kernel and network interface card firmware depends on the architecture used. For convenience, Fig. C depicts this organization on our devices where the full MAC firmware resides on the wireless cards, while the upper layers reside in the host OS kernel. In the figure, diamonds represent packet classifiers, while circles represent packet schedulers. The data flow from left to right is outgoing packets originating from the applications to the wireless medium; the data flow in the opposite direction is incoming packets that are routed or delivered to the applications. Packets in the slotted wireless medium (far right), which are neither incoming nor outgoing, represent transmissions between two other nodes in the network.

Congestion Control and Flow Scheduling: Locally originated packets first pass through a flow classifier, represented by the left most diamond in Fig.5.

Each flow has two individual queues, namely, a pre-queue (PreQ) and a flow queue (FlowQ). After classification, packets are inserted into the PreQ and must pass through the congestion controller, represented by the faucet handle in the figure. Congestion control is performed depends only on the length of the local FlowQ. A longer FlowQ reduces the allowed input rate, while a shorter FlowQ allows a higher rate. After congestion control, packets enter the FlowQ and wait to be scheduled. The kernel-space packet scheduler is synchronized with the slottedMAC with respect to time and link queue state. Just shortly before a scheduled transmission slot starts, the kernel scheduler dequeues a packet from the scheduled FlowQ and sends it down to the firmware link queue for transmission.

Link Scheduling

The MAC protocol keeps an individual queue for each neighbor in order to enable link scheduling, which allows a higher spatial reuse than node scheduling. As packets dequeued from the FlowQ arrive at the link-level packet classifier, they are classified according to the destination MAC address and inserted into the appropriate link queues (LinkQ). The slotted MAC, realized by a TDMA MAC protocol maintains network-wide node synchronization and ensures that transmissions occur strictly within slot boundaries. When a transmission slot starts, the MAC protocol dequeues a packet from the scheduled LinkQ and transmits it over the air. If the transmission fails and the retransmission limit is not reached, the packet remains in the appropriate LinkQ until the next slot for the same neighbor.

Packet Reception and Forwarding:

Once a packet is received, it is first filtered based on the destination MAC address and then inserted into a single receive queue (RxQ) at the firmware. The packet is delivered to the network layer at the kernel, where it is routed and tagged for local delivery or forwarding. In the latter case, the packet is inserted into the respective FlowQ and waits to be scheduled, just like a locally generated packet after passing congestion control.

Cross Layer Queue Synchronization:

Implementing link scheduling at the firmware is challenge due to the limited memory of wireless cards. As a result, the Kernel and the firmware must be tightly synchronized with respect to both memory utilization, time to avoid memory exhaustion blocking and slot utilization. Memory exhaustion blocking occurs if a given LinkQ has accumulated for many packets, leaving no memory space for other queue, once the firmware memory is full, no packets can be sent from the FlowQ's to any LinkQ. At the same time the kernel must send the sufficient number of packet to populate the different LinkQ of the upcoming slots. In this case transmission slots will remain unused if the scheduled LinkQ is empty. So we present a cross layer queue synchronization to address these issues, the firmware periodically advertises its LinkQ length as well as the current time slot to the kernel. This occurs at every slot for a tight synchronization, then the kernel uses this information to send each packet to the firmware just two slots before its actual transmission, unless the corresponding LinkQ already has a sufficient number of packets in its queue.

CONCLUSION

The great number of cross-layer approaches that address the challenges presented by the new applications of WSNs proves that there is still need for further optimization of these networks, and that cross-layering is efficient to accomplish that. Thus, in this survey most of the recent research on this field has been gathered and discussed. Proposals have shown that there are different categories of WSNs, and that each of them has their own set of problems to be addressed. Furthermore, well-known problems have been discussed and some available cross-layer solutions have been briefly presented. We also intend to evaluate XPRESS in future for larger networks. We believe our work opens up interesting avenues in wireless network system design, showing that optimal centralized routing and scheduling are feasible for small- to medium-sized wireless multihop networks.

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