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An Enhanced Cross Layer Architecture for Wireless Multihop Networks

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ABSTRACT: Imperfect scheduling and out-of-order packet delivery makes contemporary cross-layer backpressure architecture to operate at much below their capacity because they do not support TCP . In this paper, we proposed XPRESS-TTT ,a throughput optimal cross layer backpressure architecture with TCP support designed to provide maximum throughput of network also provide a coordination among networks.TCP can be operated on top of XPRESS-TTT because it is implemented at IP layer . In XPRESS-TTT, just like XPRESS network architecture here also a mesh network is transformed into a wireless switch, where packet routing and scheduling decisions are made by a backpressure scheduler. The Proposed XPRESS-TTT avoids out-of-order packet delivery and variable packet size, optimally load-balances traffic across them when congestion occurs, improving data rate among networks. XPRESS-TTT signals congestion by sending a congestion indicator to TCP whenever the TCP windows size reaches over the optimal size of window so we avoid transmitting packets through the network and wasting the wireless resources, only to drop them at the congestion queues further down the network. XPRESS-TTT uses TCP as transport protocol which establishes dedicated connection between source and destination which then avoids out-or-order delivery in multipath routing. Our simulation result shows that XPRESS-TTT gives 60% more throughput than XPRESS.

KEYWORDS: Backpressure scheduling and routing,TCP,congestion control,wireless multihop network.

I. INTRODUCTION

Existing XPRESS networks are designed to provide coordination between each layer of the network stack. This approach avoids congestion at upper layers, but end-to-end performance can be very poor due to out-of-order packet delivery and variable packet size [1]. This is especially true for wireless multipath networks where packets traverse several consecutive links.

The main design challenge is to handle out-of-order packet delivery and variable packet size in order to efficiently use network resources while guaranteeing fairness among users.

There is a large body of recent theoretical work that explores back-pressure scheduling in context of utility maximization [17]. The back-log represents the queue sizes at nodes, and the main idea of back-pressure scheduling is to give priority to links and paths that have higher back-pressure, defined as the differential back-log at consecutive nodes. If we assign a ‘utility’ to each flow, which is a function of the flow’s rate, then utility maximization seeks to design network protocols that will maximize the aggregate utility.

In this paper, we present XPRESS-TT, throughput-optimal backpressure architecture with TCP support for wireless multihop networks. In XPRESS-TT, just like XPRESS network architecture here also a mesh network is transformed into a wireless switch, where packet routing and scheduling decisions are made by a backpressure scheduler. XPRESS-TT consists of a central controller, which does 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.

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The XPRESS-TT cross-layer stack integrates the transport, network, and MAC layers which avoids congestion at upper layers. In order to handle out-of-order packet delivery and variable packet size we implement TCP on the top of EXPRESS-TT as transport protocol. Then the backpressure algorithm was introduced as a scheduling policy. Backpressure algorithm is a centralized method for directing traffic around a queuing network that achieves maximum network throughput in wireless multihop networks.

Finally our simulation work shows that XPRESS-TT provides perfect optimal backpressure schedule and delivers the packets with minimum end to end delay than existing XPRESS architecture

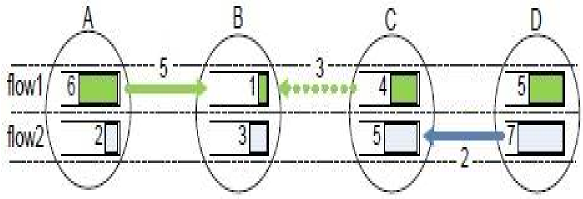

Fig. 1. Backpressure scheduling in a network with two flows

II. RELATED WORK

Backpressure Architectures: The backpressure algorithm was introduced by Tassiulas and Ephremides [1], and since then, a significant effort has been dedicated to distributed approximations that guarantee a fraction of the capacity region [12]. These algorithms maintain the slotted TDMA MAC protocol assumption of the original algorithm, but have not yet been translated to real implementations. On the other hand, recent work applies backpressure concepts to build practical systems. For instance, Wu *et al.* [13] prototype a synchronous and distributed SIR-based maximal matching MAC scheduler on a DSP/FPGA platform. In a different approach, several systems have been built on top of existing MAC protocols, such as 802.11. Akyol *et al.* [2] modify the 802.11 contention window to prioritize links with a higher differential backlog. Radunovic *et al.* [3] enhance the performance of multipath TCP transfers with a simplified backpressure scheme on top of 802.11. In a similar fashion, Aziz *et al.* [14], Ryu *et al.* [19], and Warrier *et al.* [4] approximate backpressure scheduling using prioritization in 802.11. Moeller *et al.* [16] build a backpressure routing architecture over 802.15.4 to enhance data collection in wireless sensor networks. More recently, Bhorkar *et al.* [17] and Choumas *et al.* [17] propose 802.11 backpressure implementations to reduce the end-to-end delay. Most of these works [2]–[4], [14], [17], assume a separate routing protocol.

TCP over wireless network: One of the first analysis of TCP over a single wireless link is given in [5]. An experimental analysis of TCP performance in wireless multi-hop networks is given in [9]. They find that RTS/CTS should be switched off to benefit performance and that one should not let the retransmission counter grow too large since otherwise bad links get too much transmission opportunities. Sender-side modification of single-path TCP is proposed in [12]. It estimates bandwidth and adapts the window to the estimated value upon triple ACK receipt.

Some practical results on flow control and single-path routing in mesh networks are given in [9, 14, 15]. In [11], back-pressure is used in a different manner to prevent congestion at MAC layer. It requires MAC-layer modifications and is verified by simulations only. Similar results that prevent MAC-layer contention using flow control are presented in [9, 15].

Multi-path routing in sensor networks has been proposed in [16]. It requires coordinates and provides disjoint paths based on the topology. It has its own flow control scheme, does not use TCP. Multi-path routing with TCP has been proposed in [24]. It measures RTT on each path and sends traffic proportionally to RTT tested by simulations only and in lightly-loaded network (no reordering). There is a long history of multi-path routing and TCP in wired networks. Some of the examples are [6, 8, 10]. In [8] a flow level balancing is proposed to avoid reordering effects. [6] Proposes a multi-path load balancing scheme under predefined weights that minimize average packet delays. A way of preventing reordering and timeouts in TCP using DSACK is discussed and a theoretical analysis of multi-path in wired networks is given in [10].

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Originally, back-pressure scheduling has been proposed in [20], where it is shown that this scheduling can stabilize a network whenever possible. This paper generated a whole new direction of research on the jointly optimal scheduling, routing and flow control in wireless networking (c.f. [7, 8, 15, and 17]); a comprehensive survey can be found in [7]. A modification of the MAC layer using the back-pressure approach is presented in [2] and evaluated by simulations.

III. BACK PRESSURE SCHEDULING

The backpressure algorithm is an optimal routing and scheduling policy that stabilizes packet queues with capability to achieve the maximum throughput. The backpressure algorithm dynamically selects the set of links to activate and flows to transmit on these links depending on queue backlogs and channel rates. In the following, we consider its application to a time-slotted wireless network. Assuming slotted time, the basic idea of backpressure scheduling is to select the "best" set of noninterfering links for transmission at each slot.

Fig. 1 shows an example of how the backpressure algorithm works: nodes A, B, C, and D form a three-hop wireless network with two flows (flow 1 and flow 2). Each node maintains a separate queue for each flow. For each queue, the number of backlogged packets is shown. Each node has the same transmission rate and cannot transmit and receive at the same time slot. At a time slot, the backlog of each node for each flow is illustrated in Fig. 1.

The backpressure algorithm works as follows. First, compute the maximum differential queue backlog between each node pair as a link weight .For example, for link (A, B), the flow 1 has a difference of 5 packets and the flow 2 has a difference of 3 packets.

The maximum value is then assigned as the weight of the link (see Fig. 1). ; i.e., A→B is 5 for flow 1, C→B is 3 for flow 1, and D→C is 2 for flow 2, and select these three links. Second, list all non-conflicting link sets, i.e., {A→B for flow 1, D→C for flow 2} and {C→B for flow 1}. Finally, choose the set that maximizes the sum of all link weights, i.e., {A→B for flow 1, D→C for flow 2}.Finally, packets from the selected flows are transmitted on the selected links.

2.1 Backpressure Algorithm

More formally, the backpressure scheduling algorithm consists of the following steps executed for each time slot.

Flow Scheduling and Routing: For each link (i, j), select the flow f_{ij}^* with the maximum queue differential backlog

$$f_{ij}^* = arg \max_{f \in F}(q_i^f - q_j^f) \qquad (1)$$

Where q_i^f and q_j^f are the queue backlogs for flow f at nodes i and j , respectively, and F is the set of flows. The maximization in (1) implicitly performs routing by selecting the link (i, j) that each flow may use during the slot. The weight w_{ij} of each link is then selected as the weight of flow f_{ij}^*

$$w_{ij} = \max_{f \in F}(q_i^f - q_j^f)(2)$$

Link Scheduling: Select the optimal link capacity vector $\mu^*= (\mu_{ij}^*)$ that satisfies

$$\mu^* = \max_{\mu \in A} \Sigma_{(ij)} \mu_{ij} w_{ij} (3)$$

Where $\mu = (\mu_{ij})$ are the link capacity vectors. The capacity μ_{ij} of each link (i, j) is the maximum rate in bits per second that the link can transmit subject to the channel state and the interference due to the other links in the vector. The set of all feasible link capacity vectors define the capacity region A.

Transmission: During the time slot, a selected link (i, j) transmits a packet from flow f_{ij}^* using rate μ_{ij}.

IV. XPRESS-TT DESIGN

This section presents the XPRESS-TT design and implementation. EXPRESS-TT architecture composed of more mesh access points (MAPs), some gateways (GWs) and a mesh controller (MC), as shown in Fig 2.The MAPs operates as wireless routers and provides wireless connectivity between mobile nodes. The MAPs is responsible to forward user traffic. Mobile clients communicate with MAPs over TCP. The GWs are connected between both wired and wireless

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network and provide bridge between two. The GWs coordinates the communication between wireless network and wired infrastructure.

The MC is responsible for overall communication of wireless network. It coordinates all the network elements in the network. The MC is deployed in a dedicated node in the wired infrastructure and connects to the gateways through high-speed links

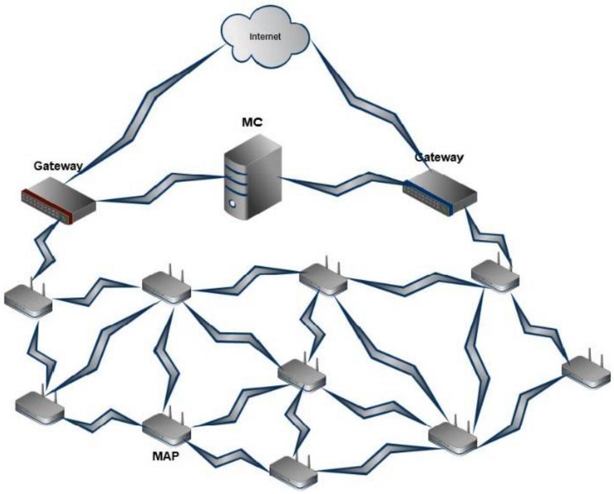

Fig. 2. XPRESS-TT architecture, composed MAPs, GWs, MC for wireless scheduling

The operation of XPRESS-TT can be described as follows. EXPRESS establishes the TCP connection between mobile nodes, GWs and MCs. Now mobile nodes send the TCP connection request to the GWs. GWs receives the connection request and placed the entire request in queue. Now XPRESS-TT runs a slotted MAC protocol, where a sequence of slots is organized into *frames*. For each slot XPRESS selects a set of no interfering links to transmit based on the flow queue lengths and network state. Each node thus maintain queues to store the request and monitors adjacent links to estimate interference and losses.

The queue length and adjacent node monitoring results are periodically transmitted to the MC. This information is sent by uplink control channel. The MC receives this information and update its local topology and interference databases and runs backpressure scheduler to calculate the throughput-optimal schedule for multiple upcoming slots. Then the MC transmits the computed schedule to the nodes. Here MC uses downlink control channel to transmit computed schedule to nodes. Finally nodes apply the new schedule for transmission in the slots of the next frame. This process then repeats periodically.

XPRESS-TT flows are defined at IP layer by its source and destination mesh nodes. Here TCP is used as transport protocol. 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.

V. INTERACTION WITH TCP

This section presents how the TCP is interacted with XPRESS-TT. Firstly, TCP needs to react when a network is congested, decrease the window in order to prevent congestion collapse and enforce fairness. XPRESS-TT does flow control and sends a congestion indicator to TCP whenever it senses congestion. Secondly, TCP expects to receive packets in order and within some time-frame to avoid timeouts. XPRESS-TT delays packet delivery to minimize reordering and timeouts.

Congestion control and fairness: One of the goal of TCP is to detect and avoid network congestion. Another goal is to guarantee fairness among flows. TCP achieves both these goals by reacting to packet losses. Here each packet loss is treated as a congestion loss. XPRESS-TT signals congestion by sending a congestion indicator to TCP whenever the

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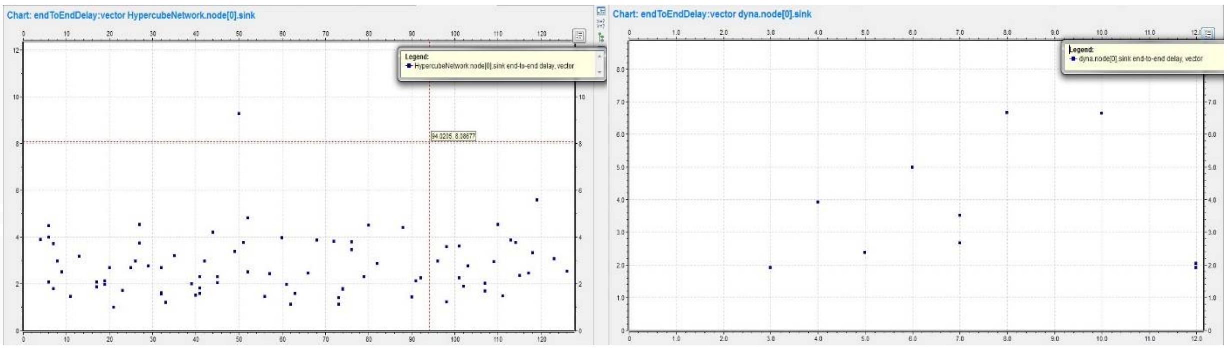
TCP windows size reaches over the optimal size of window so we avoid transmitting packets through the network and wasting the wireless resources, only to drop them at the congestion queues further down the network.

Out-of-order delivery and Timeouts: It is well known that out-of-order delivery reduces the performance of multipath routing as it causes extra burden to network by rearranging the out-of-order packets. So Here XPRESS-TT uses TCP as transport protocol which establishes dedicated connection between source and destination which then avoids out-or-order delivery in multipath routing. To avoid TCP timeouts, here we use delayed reordering algorithm. The delayed reordering procedure cannot completely eliminate timeouts when one path is significantly delayed or lossy. However, it significantly reduces the rate of these undesirable events to the point that we can efficiently explore multiple paths and outperform single-path TCP in many cases.

Variable packet size: One of the most important functionality of TCP is *fragmentation*. Fragmentation is the process split the packets into fixed size fragments. As we addressed that the existing XPRESS does not support variable packet size so here we use TCP's fragmentation functionality which splits variable size packet into fixed size fragments.

Detecting Wireless Losses: Packet missing is common thing in wireless network due to wireless loss so it is very important to establish method to find out packet loss. In XPRESS-TT packet loss is find out by inspecting a packet at the destination and we can detect if it consists of TCP ACK or a TCP window probe.

VI. PERFORMANCE EVALUATION

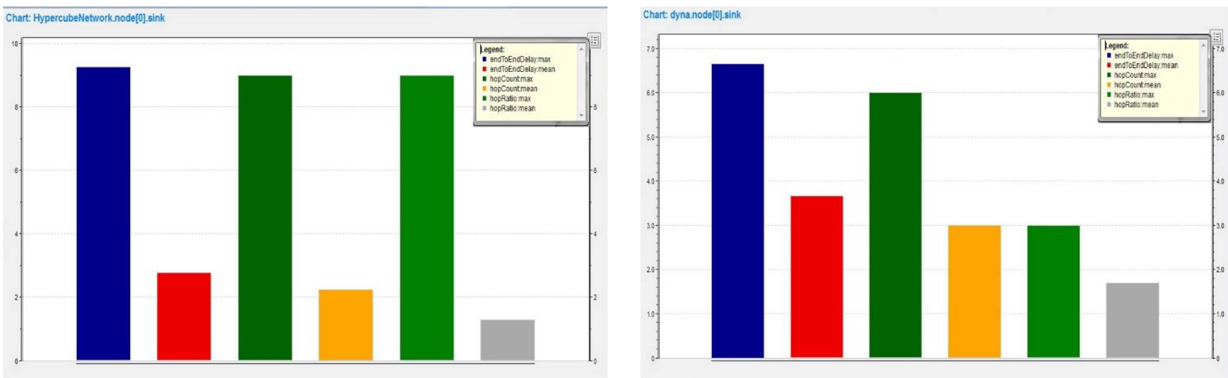


a) XPRESS end to end delay

b) XPRESS-TT end to end delay

Fig. 3. End to end delay comparison between XPRESS and XPRESS-TT

Fig 3 shows that XPRESS-TT achieves less end to end delay than XPRESS and Fig 4 indicates that XPRESS-TT achieves better performance than XPRESS.



a) Performance metrics analysis of XPRESS

b) Performance metrics analysis of XPRESS-TT.

Fig.4. Performance analysis of XPRESS-TT over XPRESS

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We simulate the performance of XPRESS-TT on OMNET++ tool. We simulate the XPRESS-TT with 8 mesh access points, 2 gateways and mesh controller as shown in the Fig. 5.

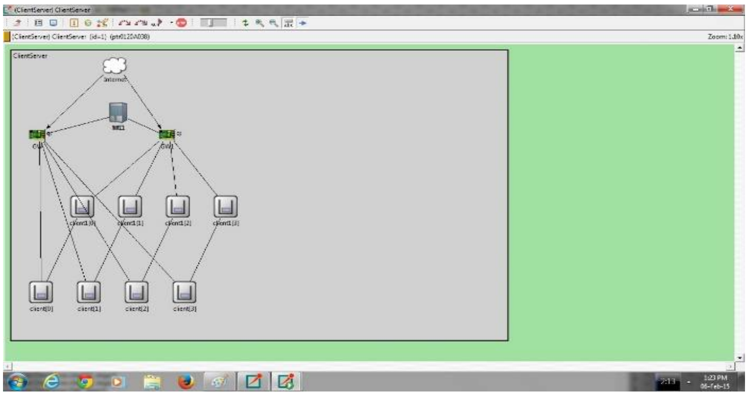

Fig. 5. XPRESS-TT simulation on OMNET++

Performance Metrics: We use three performance metrics to evaluate the overall performance of XPRESS: **end to end delay** max mean**, hop count** max mean, **hop ratio** max mean. Our simulation result shows that XPRESS-TT gives 65% more throughput than XPRESS.

VII. CONCLUSION

We presented the design and implementation of XPRESS-TT, throughput optimal backpressure architecture with TCP support for wireless multihop networks. In contrast to previous work, we provided a throughput optimal backpressure with TCP support to reach maximum throughput of wireless multihop networks and we avoided out of order packet delivery, Congestion and variable size packet handling problem. Our simulation results confirm that XPRESS-TT provides better performance than existing EXPRESS.

In backpressure scheduling, there are no pre-established routes; the route taken by a packet depends on the network congestion. As a result, packets may visit the same node more than once and create loops. This is particularly common in under loaded networks. New delay reduction techniques [16], as well as an analysis of their throughput–delay tradeoffs are then required to serve both elastic and inelastic traffic so this will be the future work.

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