Promoting Fluidity in the Flow of Packets of 802.11 Wireless Mesh Networks

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ABSTRACT

Wireless Mesh Networks (WMNs) are based on packet forwarding and therefore require efficient multi-hop protocols for their deployment. Toward this objective, we study the flow of packets through the network and using an analogy with fluid physics we classify them as being either laminar in the case of a smooth propagation or turbulent otherwise. Following this terminology, we present the tendency of current 802.11 to generate turbulent flows, i.e. to queue packets at the intermediate nodes for a non-deterministic time. However numerous applications such as VoIP, TCP and streaming are very delay sensitive and therefore laminar behavior is desirable. We model existing 802.11 multi-hop networks and identify the exponential backoff policy as a main parameter in the transition between laminar and turbulent behavior.

1. INTRODUCTION

Wireless mesh networks with their promises of delivering high throughput wireless coverage at low cost are getting an increasing attention from both academia and industry. Despite our extended knowledge of single-link communication between the AP and users, we still ignore the exact behavior occurring in the multi-hop backhaul of a WMN. In particular the requirement of backhaul nodes to forward traffic to and from a wired gateway leads to new challenges inexistent in traditional single-hop networks, such as fairness, efficiency and flow starvation.

To improve the current performance of WMN backhauls, a good understanding of the limitations of the existing policies is needed. We focus our analysis on the MAC layer and study the behavior of a packet through a multi-hop network in order to deliver high throughput and low delay. Using fluid physic terminology, we identify the exponential backoff of 802.11 as the source of the problem and propose a simple modification of the 802.11 protocol to solve it.

2. PACKET FLOW ANALYSIS

2.1 Problem statement

WMNs can be divided in 2 parts: backhaul and access. We consider that each node is equipped with 2 wireless cards running on orthogonal channels: one channel dedicated to connect the users to the access points and the other reserved for the backhaul network under the control of the service provider. The role of the backhaul is to wirelessly transport the users' data to the Wired Access Point (WAP) over multiple hops on Transit Access Points (TAPs). WMNs are modeled as a k-tree with the WAP as root. For simplicity reasons, we consider linear topologies where the WAP is located at the extremity (k=1) or center (k=2) of the topology. These linear topologies are an efficient architectural choice for the deployment as it significantly reduces the level of contention among TAPs. Furthermore, results can easily be extended to more general k-tree topologies by requiring parallel branches of the tree to run on orthogonal channels

2.2 Desirable flow behavior

The performance metrics that we consider for backhaul networks consist of maximized end-to-end throughput and minimized delays and packet loss, particularly important for delay sensitive protocol such as TCP or VoIP.

We argue that the nature of the packet flow, i.e. the packet evolution from one node to the next one, plays a key role. In particular, following fluid physics terminology, we denote the flow as being either *laminar* or *turbulent*.

DEFINITION 1 (LAMINAR FLOW). *Laminar flows are characterized by a smooth propagation of packets, where every packet only spends a negligible time in any TAP's buffer. They satisfy the following condition on the buffers B_i:*

$$Prob(B_i\, full) \approx 0 \qquad \forall i \neq WAP \tag{1}$$

The opposite of laminar flows are *turbulent* flows:

DEFINITION 2 (TURBULENT FLOW). *Turbulent flows are characterized by packets spending a significant amount of time in the buffer of TAPs and high packet drop rate.*

$$Prob(B_i\, full) \gg 0 \quad for\, at\, least\, one\, i \neq WAP \tag{2}$$

To motivate our argument of promoting laminar flows we use a vehicular traffic analogy based on the model presented in [2], where packets are seen as vehicles. Under ideal conditions, all cars travel at constant speed on the road without

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being blocked at a traffic light or by a traffic jam. This scenario clearly leads to lower travel time and higher total road debit than the start-stop-wave created by traffic jam.

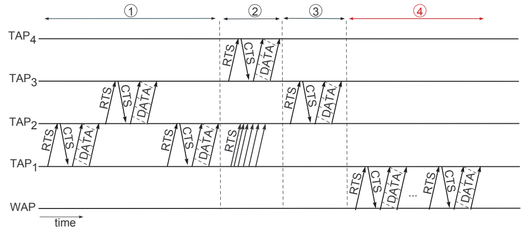
Reverting back this scenario to a backhaul network, laminar flows avoid blocked packets at the TAPs buffer and therefore experience better performances than turbulent flows suffering the drawbacks from the start-stop-wave behavior.

3. MAC PROTOCOLS IN EXISTING MULTI-HOP BACKHAUL NETWORKS

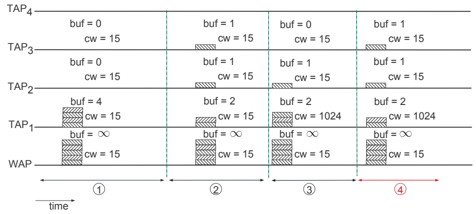
In multi-hop scenarios, the flow behavior can be influenced at the application layer by using rate control [3, 4]. However, we argue that this behavior is determined by the MAC layer. Therefore it is necessary to understand the behavior of existing protocols and adapt them to WMNs.

3.1 Limitation of 802.11 protocol

The current 802.11 standard was designed for single-hop communication and therefore is not optimized for forwarded packets which are common in WMNs. These particularities of multi-hop traffic lead the WMNs using standard 802.11 to experience turbulent flows and therefore to only reach significantly sub-optimal performances.



(a) Link activity. ACK messages are voluntarily omitted for readability purpose.



(b) Buffer size and *cw* evolution at the beginning of each phase

Figure 1: Illustration of the turbulent flow creation due to the exponential backoff of MAC 802.11. TAP_1 fills up its buffer because of the high *cw* value relatively to the other nodes.

In particular, the exponential backoff mechanism of 802.11 is responsible of filling up the buffer of TAP_1, leading to a high number of dropped packets and a turbulent flow.

The phenomena depicted in Figure 1 and leading to an unfair competition between the first and second link can be prevented by two approaches.

3.2 Idealized approach

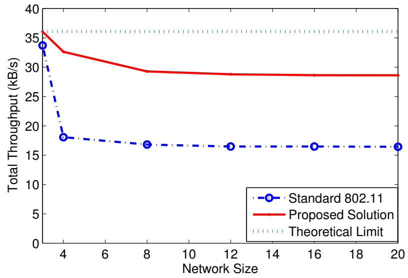
An idealized solution is the use of a central entity that schedules the nodes using a slotted access protocol such as TDMA to guarantee a smooth propagation of the packets.

Such approach can therefore achieve performances matching almost perfectly the system capacity. However practical difficulties such as (i) uncontrollable interference and (ii) multi-hop time synchronization limit the use of centralized solution in reality.

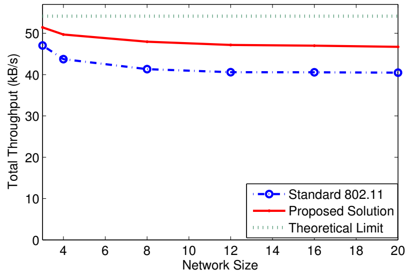
3.3 Realistic approach

The requirement of a central authority is however not mandatory for the promotion of laminar flows in the network. Instead, simple modifications of the parameters of 802.11 can achieve it by: (i) fixing the contention window ($cw_{max} = cw_{min}$) and (ii) increasing the short retry limit (maximal number of attempts before dropping a packet).

The performance improvements of this protocol have been verified by both simulations (Figure 2) and measurements on a 5-nodes wireless testbed [1].



(a) 1-ary topology.



(b) 2-ary topology

Figure 2: Performance gain achievable by removing the exponential backoff policy and increasing the *short retry limit*.

4. REFERENCES

[1] A. Aziz, R. Karrer, and P. Thiran. *Effect of 802.11 adaptive exponential backoffs on the fluidity of downlink flows in mesh networks*. Technical Report LCA-REPORT-2007-009, EPFL, 2007.

[2] K. Nagel, and M. Schreckenberg, *A cellular automaton model for freeway traffic*. In *J. Phys. I France 2*, pp. 2221-2229, December 1992.

[3] P. C. Ng, and S. C. Liew, *Throughput Analysis of IEEE802.11 Multi-hop Ad hoc Networks*. In *ACM Transactions on Networking*, April 2007.

[4] L. Li, and P. A.S. Ward, *Structural Unfairness in 802.11-based Wireless Mesh Networks*. In *CNSR'07*, New Brunswick, Canada, May 2007.